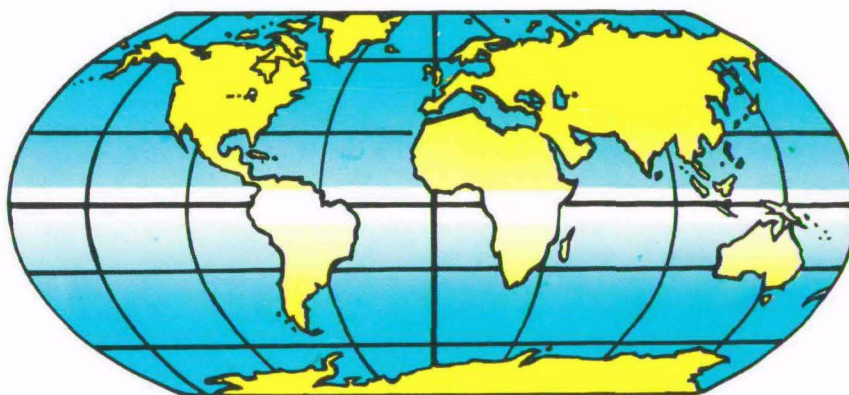


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# ***Reducing Risk in Paint Stripping***



**Proceedings of an International Conference**

***February 12-13, 1991  
Washington, D.C.***



Economics and Technology Division  
Office of Toxic Substances  
U.S. Environmental Protection Agency  
Washington, D.C.

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**Proceedings of an**  
**International Conference on**  
**Reducing Risk in Paint Stripping**

***February 12-13, 1991***  
***Omni Shoreham Hotel***  
***Washington, D.C.***

**Economics and Technology Division**  
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# **Introduction**

**T**he International Conference on Reducing Risk in Paint Stripping represents the first in a series of planned meetings and exchanges sponsored by the Office of Toxic Substances at the U.S. Environmental Protection Agency (EPA). It is my belief that the exchange of information among individuals from industry and government, both domestic and international, represents one of the most efficient and effective methods of achieving our goals of reducing human health risks and environmental pollution.

I am grateful for the enthusiastic response of participants at this conference. Many of you who took part in the discussions remarked that you were pleased with the new cooperative initiatives taken by EPA to promote information sharing and learn about industry developments in risk reduction. It is my hope that information gained at the conference will translate into new developments in industrial technologies. In addition, I hope this exchange of ideas will lead to the realization of opportunities to use existing risk reduction technologies while still meeting the technical needs for coatings removal.

The Office of Toxic Substances would like to thank all those who participated from both the private and public sectors. In particular, we thank the international participants who attended the conference from Australia, Canada, France, Germany, Japan, the Netherlands, Switzerland, and the United Kingdom. I would like to extend our special thanks to those agencies that helped to coordinate the program and chair the individual technical sessions: the U.S. Consumer Product Safety Commission, the National Institute for Occupational Safety and Health, and the Occupational Safety and Health Administration.

Finally, for those of you who came away from the paint stripping conference with new contacts in government and industry or new processes for application to industrial paint stripping needs, we would like to hear from you. Specifically, we would appreciate any information that documents changes in your industry, business practices, or thinking about pollution prevention that were instituted as a result of attending this conference. Have you changed a process or added any new equipment for coatings removal or paint stripping waste management, taken any additional measures to reduce solvent exposures in the workplace, or tried any new substitute chemicals or paint removal processes to evaluate their effectiveness? Let us know how

your efforts in pollution prevention and risk reduction have been furthered as a result of this conference. We are eager to continue the communication process and expand on the transfer of information. Please contact the Office of Toxic Substances to share details of your progress in pollution prevention and risk reduction.

Thank you again for your cooperation in this new endeavor. We will hope to hear from you and look forward to hosting additional technical information sharing conferences in the future.

**Mark Greenwood**  
*Director*  
*Office of Toxic Substances*  
*U.S. Environmental Protection Agency*  
*Washington, D.C.*

# ***Foreword***

**T**he International Conference on Reducing Risk in Paint Stripping was held on February 12-13, 1991, in Washington, D.C. Sponsored by the U.S. Environmental Protection Agency, cooperation and support from the National Institute for Occupational Safety and Health, the U.S. Occupational Safety and Health Administration, the U.S. Consumer Product Safety Commission, and the Halogenated Solvents Industry Alliance helped produce a productive and successful conference.

This conference focused on managing the use of chemical paint strippers and was intended to identify and promote ways to reduce risks associated with these paint strippers. Serving as a forum for discussion of exposure controls, paint stripper substitutes, and alternative technologies, topics included substitutes for methylene chloride paint strippers; product stewardship programs of methylene chloride producers; opportunities for pollution prevention in paint stripping; and government activities in the United States and other countries. Conference participants included an international group of chemical producers, paint stripper formulators and users, producers of mechanical and other alternative paint stripping technologies, public interest groups, and government officials.

These proceedings contain transcribed talks and copies of the papers presented during the conference. The conference format included both plenary and breakout sessions to address concerns in original equipment manufacturing, maintenance usage, and consumer and household usage. This format is reflected in the organization of these proceedings. Presentations provided to us in written form are included in these proceedings. Typed summaries of the verbal remarks made at the conclusion of the breakout sessions also have been included to provide a more complete picture of the information and views exchanged. An opportunity was provided for the inclusion of information not presented during the conference; these additional papers can be found in Appendix B: Supplemental Information.

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# **OPENING SESSION**



# Introductions and Opening Remarks

## **Mary Ellen Weber**

*Office of Toxic Substances*

## **Linda Fisher**

*Office of Pesticides and Toxic Substances*

## **Charles Auer**

*Existing Chemical Assessment Division, Office of Toxic Substances  
U.S. Environmental Protection Agency  
Washington, D.C.*

### ■ **Mary Ellen Weber**

As the recently appointed director of the Economics and Technology Division in the Office of Toxic Substances, I'm delighted to welcome all of you to our first international conference on reducing risk in paint stripping.

At the Environmental Protection Agency (EPA), the Office of Toxic Substances is responsible for carrying out the Toxic Substances Control Act. Specifically, we manage the use of chemicals in such a way that society can reap their benefits without facing unreasonable risks.

We at EPA, along with our sister national and international agencies, are increasingly concerned about the risks to human beings who are exposed to methylene chloride and other chemical substances associated with paint stripping. Therefore, we are excited to learn about new developments that make it possible to both reduce risks and prevent pollution. Now in its third decade, EPA is concentrating increasingly on pollution prevention and risk reduction as complements to our traditional policy of end-of-the-pipeline treatment.

The purposes of this conference, therefore, are to share information, promote the transfer of technology, and present and compare costs and technical feasibilities of alternative methods and approaches to paint stripping. It is not the purpose of this conference to discuss specific risk numbers.

Before joining EPA, I spent a number of years at the Occupational Safety and Health Administration (OSHA), where I conducted economic and technological feasibility analyses. At OSHA, I had the pleasure of working closely with my counter-

parts at the Consumer Products Safety Commission and the National Institute for Occupational Safety and Health. I want to thank OSHA, CPSP, and NIOSH for their participation in this conference. We're grateful for their support and their help in coordinating other federal agencies and identifying participants and speakers.

In a few minutes, I will have the privilege of introducing my boss's boss, but before that, I'll run briefly over the agenda.

We will begin the conference by looking at an overview of the risk considerations associated with paint stripping. After that, we will hear how various U.S. government agencies are attempting to reduce risks associated with paint stripping.

Today, pollution problems are international in scope. For that reason, we have a panel who will discuss the Organization for Economic Cooperation and Development's (OECD's) activities regarding paint stripping and pollution prevention approaches and techniques. Labor will then speak to us about concerns for workers' exposure. Finally, we will hear from a panel, appropriately conducted by industry, on product stewardship. Product stewardship is a new idea at EPA; it involves taking responsibility for the entire life cycle of a chemical. No longer are we just interested in cleaning things up. We want to follow the chemical from its birth to its disposal—to be responsible for the chemical throughout its life cycle of production, distribution, and use.

This afternoon and tomorrow morning, we will be splitting into three groups: original equipment manufacturing, maintenance, and household and commercial. The panel discussions will focus on

reviewing current paint stripping practices, alternate chemicals and other technological substitutes, and various risk reduction and pollution prevention techniques for each of these sectors. Tomorrow afternoon when we meet in full session, we will summarize what we have learned in these panels. We will concentrate on what we can take home with us and apply, such as techniques, methodologies, and risk reduction opportunities we have learned here.

We plan to produce proceedings of this conference and want to include as much information as possible. We encourage all of you who have information of a technical nature—product specification, cost information, feasibility information of alternative methodologies, techniques, and products—to give it to our contractor, Abt Associates. In that way, we can promote our goal of sharing information and disseminating it as much as possible.

Now, I have the pleasure of telling you a little bit about Linda Fisher. Linda is the assistant administrator for the Office of Pesticides and Toxic Substances (OPTS) at EPA. Before that, she was the assistant administrator for the Office of Policy Planning and Evaluation. Linda joined EPA as the chief of staff and special assistant to former Administrator Lee Thomas. Before coming to EPA, she was an associate staff member for the House Appropriations Committee and a legislative assistant in the offices of Congressman Ralph Regula and Congressman Clarence Brown. A native of Columbus, Ohio, Linda is a graduate of Miami University; she received an MBA from George Washington University and earned a juris doctorate degree from Ohio State University's College of Law in 1982. She is a member of both the Ohio and D.C. bars. It's an honor and a pleasure to work for a woman of high integrity and intellectual acumen—and, best of all, she has a terrific sense of humor.

### ■ Linda Fisher

Again, I'd like to welcome all of you to our conference and to extend a special warm welcome to our international visitors. We really appreciate you coming.

Our conference here today does reflect a major change in and approach to managing chemical risks in the United States. The Toxic Substance Control Act (TSCA), the statute under which we regulate chemicals, is one of the most powerful that EPA administers. Our office is responsible for managing and assessing the risks of over 60,000 industrial chemicals. How we identify hazards

from these chemicals, how we assess risks, and how we manage them pose increasingly complex problems. More and more we find ourselves asking questions such as: What are the safer substitutes for these chemicals? How can we encourage people to use them? Are there better ways to reduce exposure than we have identified in the past?

As we all know, the typical "command and control" approach that we have so often used at EPA is slow and tedious—frustrating for the consumer, the government regulator, and industry. New concepts in risk reduction are needed—and this conference will illustrate some that are of growing importance to EPA.

The first of these concepts is pollution prevention. It is not end-of-pipe control, designed to minimize harm from pollution after it has been created. Instead, more and more at EPA, we are asking the question, how can we prevent the pollution, or the risk from pollution, from occurring in the first place?

We also are beginning to examine chemical hazards from a broader base than before: we are examining risks to consumers, to workers, and to the environment and trying to focus broadly, rather than shifting the risks from one medium to another or from one population to another.

We are also increasingly aware of the importance that information sharing can play in reducing risks. Government agencies sharing their information with each other and with industry and both of us sharing our information with the public oftentimes can create very successful risk reduction opportunities.

Lastly, more and more we see the importance of international cooperation—rarely is an environmental problem limited to one country. Technical work on risk assessment and risk reduction technologies can be shared between industrialized nations. This will help develop cooperative and consistent actions that will reduce duplication of efforts and perhaps achieve better risk reduction for citizens of all countries.

So how did we choose paint stripping, and why methylene chloride? First of all, we thought this chemical and particular usage lend themselves to some of our new and creative approaches. Our concern with methylene chloride began in the mid-1980s when it was found to be carcinogenic to animals. EPA and other U.S. regulatory agencies, as well as regulatory bodies in other countries, began assessing the risks to human health of methylene chloride in several uses. Since the process of paint stripping resulted in high exposures to this chemical, EPA and other regulatory agencies studied risk management ac-

tivities, looking at available substitutes and exposure controls. We focused on three categories: the original equipment manufacturer, maintenance, and consumer usage.

Today, after several years of examination by government regulators, government users, and industry, significant questions about what we can and should do to reduce paint stripping risks remain. We know there are many substitute solvents in use or under consideration for use, but there are lots of questions about their effectiveness and if they create health hazards.

We know alternative technologies are being developed, but we don't always know how effective they are. In many applications where methylene chloride is still used, exposure-reduction methods have either not been discovered or have not been carried out. There are still so many unknowns—that is the primary reason for staging this conference. We are trying to promote the search for, and research into, safe and effective ways to reduce risk from methylene chloride paint strippers. This conference is our first attempt to use this medium to encourage cooperation between industry and government to reduce risks and prevent pollution in the first place. If it is true that information is power, then this exchange of information among national and international suppliers, users, and government representatives, may solve the problem of reducing unnecessary exposure to and risk from paint strippers.

We hope those attending this conference will take home new ideas and new friendships that can be used in the future to identify ways to reduce and manage risks and to prevent pollution in paint stripping applications. I wish you good luck in this conference, and I hope it is beneficial to all.

### ■ Mary Ellen Weber

Thank you very much, Linda. I am happy to introduce Charles Auer—Charlie is currently the director of the Existing Chemical Assessment Division in OTS. Before that, he was deputy director of the Health and Environmental Review Division at OTS. A chemist and a toxicologist, Charlie has extensive experience in hazard and risk assessments on experimental and existing chemicals.

Charlie is the OTS lead in international activities for EPA and a major liaison with the OECD. He has been actively involved in cooperative testing and assessment of high production volume chemicals and is instrumental in developing international approaches to hazard and risk assessment. And now Charlie will talk to us about risk factors associated with paint stripping.

### ■ Charles Auer

I, too, would like to welcome everyone here. And, repeating what the two preceding speakers have said, I hope this conference will stimulate an exchange of views and increase understanding on the question of substitutes for methylene chloride paint strippers.

My subject is the risk considerations in evaluating paint stripping alternatives to methylene chloride. The conference's focus is on managing the use of chemical paint strippers by exposure controls, pollution prevention techniques, chemical substitutes, and alternative technologies.

Discussion of risk is not a major focus of this conference, but I think we need to understand the kinds of information that will be most helpful in our search to develop alternative paint strippers so that we can advance to new products that will have fewer risks than methylene chloride.

When we evaluate methylene chloride and its alternatives, we must consider health and environmental hazards as well as the exposure potential of the various materials. We need to know the full range of risks from chemical toxicity to safety aspects. For instance, major concerns in the safety aspects of many of the substitutes are the questions of flammability, potential for exposure to the materials (which can be influenced by the volatility of the substitute material), and how effective they are in removing paint. There are also several non-chemical substitutes, alternative methods to methylene chloride paint strippers. We need to consider the kinds of risks these may present.

I'd like to review the hazards of methylene chloride (or dichloromethane). EPA has classified dichloromethane as a B2 or "probable" cause of cancer in humans. The Agency says there is sufficient evidence of carcinogenicity in two animal species even though there is inadequate human evidence. Therefore, the debate continues on the risks, especially as related to differences in the pharmacokinetics of dichloromethane, which appear to exist between the animals that were used in the cancer bioassays and the evidence that has emerged when human tissues are used. Exactly how this will be resolved is still unknown.

In addition, dichloromethane can cause other medical problems, including liver toxicity and heart, kidney, and central nervous system damage. It is a volatile material, partially because consumers and workers encounter high levels of exposure when using it as a paint stripper.

I'll now talk about some of the chemical substitutes for dichloromethane. Among those com-

pounds EPA identifies as potential high market share substitutes for dichloromethane are *N*-methyl pyrrolidone, furfuryl alcohol, and the dimethyl ester of a number of dibasic acids—adipic, glutaric, succinic.

A major risk consideration, as I mentioned, is the question of flammability. One of the strongest factors favoring methylene chloride is that it is nonflammable. Many of the major market share substitutes have high or moderate levels of flammability. We believe this is an important risk consideration when evaluating the acceptability of substitutes—given the likelihood that if highly flammable substances are used in homes and at the workplace, there's a good chance accidents will occur. The way the substance is formulated can reduce its flammability. Reducing the concentrations of the more flammable components may be a way to create nonflammable formulations. Another point is this: if information on flammability exists for several of the substitutes, EPA does not have it.

Volatility is also another important consideration; it can lead to large differences in the exposure potential of dichloromethane and the various substitute materials. As you can see, the relative volatility expands the range from substantially lower than dichloromethane for *N*-methyl pyrrolidone to equal to that of dichloromethane in the case of acetone. Although we don't have vapor pressure values for the dibasic esters, given their molecular weights, we expect them to be substantially less volatile than methylene chloride. But that information has not been developed. The other aspect of exposure is efficiency. The substitutes that are less efficient will require longer stripping periods and will use more solvent, resulting in higher levels of exposure. Therefore, a material may carry a lower toxic rating than dichloromethane; if the result from exposure and use is substantially greater than dichloromethane, you may or may not be improving the situation.

Of the major market share substitutes, only dichloromethane is known to be a carcinogen. Information on the carcinogenicity of virtually all of the substitutes is limited. Methylene chloride, as I've noted, is known to cause other medical problems. There are permissible exposure limits (PELs) and short-term exposure limits (STELs) available for methylene chloride and some of the paint stripping substitutes. Several of the substitute materials, *N*-methyl pyrrolidone and the dibasic esters, do not have PELs at this time—an example of the limited data available on those materials. Dichloromethane currently has a PEL of 500 parts per million, but a proposed revision

in this PEL to 25 parts per million would make it lower than all the substitutes, except furfuryl alcohol, whose PEL is 10 parts per million. Therefore, toluene, acetone, and methanol could be used at higher exposure concentrations and not violate occupational and compliance standards.

The Office of Toxic Substances has done a preliminary evaluation of the hazards and potential risks of the major market share substitutes. In this evaluation, we combined the data available on the substitutes and structure activity relationships, basically looking for information on related materials that may suggest the potential for adverse effects associated with one or more of the substitutes.

Potential concerns of one kind or another were identified for all the substitutes, including developmental effects, teratogenicity, neurotoxicity, and acute and chronic toxicity. Only furfuryl alcohol was identified as presenting any possible concern for carcinogenicity.

Thus we're left with this question: On one side is dichloromethane, identified by EPA as a probable carcinogen and known to have a variety of non-cancerous effects. On the other side are the substitutes—one of which EPA identifies as a potential carcinogen. However, there are a number of non-cancerous effects associated with them. What that presents is the difficulty in doing the analysis, in terms of trade-offs between cancerous and non-cancerous adverse health effects, and that's a difficult analysis at best.

It is clear that more information is needed on the toxicity and exposure potential of the substitute materials before we can do a decent assessment of the relative risks. EPA is beginning testing efforts under TSCA, section 4, on a few of the substitute materials—*N*-methyl pyrrolidone has a test rule that we're putting in place now and acetone will undergo neurotoxicity testing in the future. I should note that industry is voluntarily conducting tests on a number of the substitute materials. An example is Du Pont's work on the dibasic esters: it will be conducting bioassays, attempting to assess the toxicity of those substitute materials.

Further complicating the analyses of the substitute materials is that most of them are used as formulations containing two or more components. Because of this, the analyst must consider the potential hazards and risks of a series of mixtures, including possible interactions among the components in the mixtures. These interactions might increase the dermal penetration of some of the components, or toxic interactions might occur among the materials in the mixtures.

Because the concentrations of the substitutes will vary depending on the stripping application, there is no single, favorable mixture for a given set of components; however, a series of varying concentrations of the components might yield the desired stripping properties. This makes the analysis of the potential risks even more complicated.

In the case of *N*-methyl pyrrolidone (NMP), you typically encounter materials that contain 15 to 40 percent NMP, and, in addition, find other materials. Dichloromethane, itself, is also often used as a formulation that can have varying amounts of dichloromethane and contain, in addition, toluene, methanol, and acetone.

A general consideration in evaluating all of these substitute materials is that, in general, the commercial products of the substitutes don't appear to perform as well as dichloromethane in several of the paint stripping applications. Longer stripping times are required; others are flammable and will often only remove a limited range of the paints and coating materials. This further complicates the task of judging the risks of the substitutes.

We have just begun to study the relative risk potential of the non-chemical technologies, such as blasting and abrasives. Several of these non-chemical alternatives will be discussed in the conference. I encourage attendees when judging those alternative technologies as well as the chemically-based alternatives to consider the relative risks presented by the different-use scenarios and attempt to compare those risks to dichloromethane as well as to the substitutes.

In conclusion, when considering the risks of the substitutes—once again not the primary focus of this meeting—we need to consider the full range of health, safety, and exposure issues. None of the high market share potential substitutes clearly offers lower risk potential than dichloromethane, although several do appear promising. With the development of additional understanding about the toxicology of these materials, we may be in a position to offer more affirmative statements about the relative safety of some of the substitutes. There are substantial data gaps in the toxicity and exposure potential of various substitutes; this is a source of considerable uncertainty.

Once again, we need better understanding. EPA intends to play a role in identifying information that should be developed. I would look to our colleagues in the audience to be mindful of the kinds of information that can be most helpful in proving that a given substitute offers clearly

demonstrable reductions in risk when compared to methylene chloride.

The best prospects at this time appear to be *N*-methyl pyrrolidone and the dibasic ester formulations as substitutes for methylene chloride. These materials are likely to exhibit low flammability and volatility and neither are known or suspected carcinogens, though they have been identified as presenting various non-cancer health concerns. Substantially more information must be developed before we can evaluate, in any kind of a quantitative way, the relative risks presented by these substitute materials.

**Question** (inaudible):

**Response:** What you are talking about is, in many ways, the dilemma I face every day in my job in offering the kinds of guidance you need. I believe that EPA should do all that it can to provide the information and understanding that is needed so that manufacturers can make the right choices when formulating their products. One thing that can help us to do that is to have a better understanding of those components that are likely to be included in paint stripping formulations. If we understand those kinds of things early in the development cycle, we can work with industry to obtain the testing that is needed to understand the toxicity and resultant risks of those materials.

Unfortunately, it's a fact that toxicity of most industrial chemicals is not particularly well characterized, and as soon as you move away from the relatively small subset of well-studied industrial chemicals, you often are left with little more than acute toxicity information and perhaps a small amount of mutagenicity data, but really nothing in the way of any subchronic or chronic toxicity information.

To the extent that EPA understands developing markets, it can take steps to see that the needed information is developed, either through voluntary initiatives by the chemical industry or through regulations that would require testing. One of the things we're attempting to do, under Linda Fisher's guidance, is develop a list of those chemicals that most need data development.

**Question** (inaudible):

**Response:** I don't have any disagreement with that. In many ways, for certain of these materials, one could only support the needed testing through sale of the product; you're not going to spend a fortune to test something unless you have some idea of its market acceptability. That's the kind of thing we deal with all the time at EPA.

**INTRODUCTIONS & OPENING REMARKS**

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EPA can set up both a push and a pull for test data; EPA can, if you will, attempt to pull the data out of the industry through rules. However, I think the formulators and users can also push or encourage the producing companies, the suppliers,

to develop the information they judge is needed to allow them to make decisions in their best business interest, to use the safest materials possible that achieve the desired outcome.

# U.S. Federal Government Activities—Panel

## **Paul Campanella, Chair**

*Office of Toxic Substances  
U.S. Environmental Protection Agency  
Washington, D.C.*

## **Sandra Eberle**

*U.S. Consumer Product Safety Commission  
Washington, D.C.*

## **Fayez Hanna**

*Office of Risk Reduction, Health Standards Division  
U.S. Occupational Safety and Health Administration  
Washington, D.C.*

## **Robert Rosensteel**

*Office of Air Quality and Standards  
U.S. Environmental Protection Agency  
Research Triangle Park, North Carolina*

### ■ **Mary Ellen Weber**

Dr. Paul Campanella joined the EPA in 1985 after spending more than 15 years in research and international environmental work in Latin America and the United States. Paul was the senior water analyst in the Office of Management Systems and Program Evaluation when he first joined EPA. He became chief of the Commercial Chemicals Branch in 1987. Dr. Campanella will now introduce the members of his panel.

### ■ **Paul Campanella**

On this panel, Sandra Eberle represents the Consumer Product Safety Commission, Fayez Hanna represents OSHA, and Robert Rosensteel is from the Office of Air.

Our purpose this morning is to give you background on how EPA got involved in the solvent project and some of the things we have done as a committee to deal with chlorinated solvents. I'm going to expand the scope of my discussion beyond methylene chloride because I believe it is important to give you a context for what we're doing and why we're here.

EPA got involved in the regulation of chlorinated solvents in 1985 when the National Toxicology Program reported a positive result from a cancer bioassay on methylene chloride. About the same time, EPA listed methylene chloride as a hazardous air pollutant under section 112 of the Clean Air Act. We made a finding, in addition to that, under section 4(f) of TSCA, that occupational and ambient air exposures to methylene chloride may present a significant risk of serious and widespread harm to humans.

In October 1985, EPA, based on section 4(f), issued an advance notice of proposed rulemaking on methylene chloride. At that point, federal regulatory investigation of methylene chloride was begun by EPA in conjunction with the Consumer Product Safety Commission, OSHA, and FDA. This came together as an integrated project because we were interested in looking at what the other federal authorities were doing so that we would not duplicate each other's efforts.

Our focus was to determine whether methylene chloride presented a significant risk to human health or to the environment, to determine if regulatory actions were necessary, and what agencies would be best able to take those actions.

The initial scope of the Chlorinated Solvents Coordination Committee was to study possible substitutes for methylene chloride, and in 1985 those included trichloroethylene, perchloroethylene, 1,1,1-trichloroethane, carbon tetrachloride, and CFC 113.

In the beginning, we focused on the use categories presenting the greatest risk potential: dry cleaning, solvent cleaning (focusing primarily on electronics and metal cleaning), aerosol uses, and paint stripping. We took an integrated approach to determine which statutory authorities were best qualified for controlling risks. Obviously there was a lot of interest at the Consumer Product Safety Commission under the Federal Hazardous Substances Act; at OSHA because of the Occupational Safety and Health Act; at FDA because of the Federal Food, Drug, and Cosmetic Act; and EPA's authority came under both the Clean Air and the Toxic Substances Control acts.

When the study began, there were permissible exposure limits (OSHA PELs) on dichloromethane of 500 parts per million for an eight-hour, time-weighted average. There was also a PEL on trichloroethylene of 100 parts per million and on perchloroethylene of 100 parts per million. The two solvents carbon tetrachloride and CFC 113 were withdrawn almost immediately from analysis because, at that point, CFC 113 was already under consideration for regulation by the Office of Air and Radiation as an ozone depleter; I think that rule became final in August 1988. 1,1,1-trichloroethane remained part of the analysis initially but has since been removed because it is being regulated as an ozone depleter under the terms of the Montreal Protocol and Title Six of the Clean Air Act. Both of those chemicals will be phased out of commerce by the year 2002.

The work group conducted numerous evaluations—mainly hazard, exposure, and risk evaluations—of the very few standards; we developed exposure scenarios, analyzed those scenarios, did some economic analysis, and came up with risk management strategies for each use category. The work group did not attempt to reconcile differences in the statutory directions; instead, we chose from among the various options those we thought would best reduce risks, and when we reached that sort of a determination, we decided what agency would be the most appropriate to take action.

That brings us to the present. I will now turn the discussion over to my colleagues on the panel and ask them to briefly describe and bring us up to date on the actions taken in their respective organizations regarding methylene chloride.

In June of 1989, FDA put into effect a regulation under the Federal Food, Drug, and Cosmetic Act that prohibits methylene chloride—called “a significant cancer risk to consumers”—as an ingredient in cosmetics. FDA noted that “any cosmetic product that contains methylene chloride as an ingredient is deemed adulterated and subject to regulatory action.” That was the only action FDA has taken on chlorinated solvents.

## ■ Sandra Eberle

I will just briefly try to put CPSC's role in context for you. As Paul outlined, we have benefited from interagency attempts to coordinate actions to ascertain that the best approaches are taken for these chemicals and their potential uses and to make sure the federal government was being effective and responsible in the use of resources. CPSC has benefited from EPA's knowledge; I think that the exchange between both agencies and certainly with OSHA and FDA has been very worthwhile, and an example we will follow in many future activities.

CPSC's interest in paint strippers has been from the consumer product's side and, for methylene chloride and the other chlorinated solvents, date from before the commission's earliest days. These chemicals are regulated under a statute that pre-dates the agency, called the Federal Hazardous Substances Act, which puts the burden on the manufacturer to properly label any hazardous product introduced for use in and around households. We were aware that methylene chloride in a paint stripping product presented a hazard because it always had cautionary labeling, mainly for other ingredients like methanol, which is highly toxic and requires a skull and crossbones. Therefore, CPSC's interest in products that contain methylene chlorine was long-standing, whether they were aerosols, carburetor cleaners, or paint strippers (which certainly have the heaviest methylene chloride use and exposure).

In working together as a federal community, we were able to identify various exposure areas and determine what CPSC was doing to regulate aerosols or paint strippers containing these chemicals. (Carbon tetrachloride had been banned for consumer use for a considerable number of years; the others had other labeling issues associated with them.) CPSC issued a statement of policy that made it clear these data were sufficient to trigger new labeling for products that contained significant amounts of methylene chloride—amounts that could present a serious risk of personal injury or illness.

Our first step was to institute basic statutory requirements on the labeling for these products. Information had to be added about the new dangers associated with the use of paint strippers containing methylene chloride. This requirement for labeling all hazards, chronic or acute, has always been a part of the Federal Hazardous Substances Act; however, information about chronic hazards is not as advanced as data on certain acute hazards, such as acute toxicity.

By next year, CPSC will have completed an evaluation of methylene chloride in paint strippers and other consumer products. We have already compiled a list of product manufacturers under our jurisdiction who use methylene chloride in consumer products. CPSC will also conduct a consumer survey to get updated information on how people use these products and how aware they are of the labeling. The new instructions for use have been publicized through a variety of electronic and print media as well as speeches to community action groups.

This survey will help us to update risk assessments on methylene chloride, after which commissioners will decide whether any additional actions are needed. These actions could range from some type of product standard that limits exposure all the way to a ban on the use of the chemical. Obviously, the kind of information we are exchanging at this conference about substitutes for the consumer market and additional options that might be taken, such as product stewardship, is important to these considerations.

## ■ Fayez Hanna

OSHA will be developing a standard for controlling worker exposure to methylene chloride that will apply to every industrial segment, not just paint strippers. We plan to conduct risk assessments on toxic and carcinogenic effects and then evaluate the technological feasibility of achieving a certain level. Our draft proposal has been approved for publication in the Federal Register by the the Office of Management and Budget, pending consultation with the Advisory Committee for Construction, Safety, and Health.

Technological feasibility is the nucleus of OSHA's standards. I'm in favor of using engineering controls in some situations where we don't have sufficient information on toxicity or carcinogenicity. Most people think engineering controls and technological feasibility are limited to a fan, exhaust system, or blower; in actuality, there are several components that present many approaches to solving engineering problems. Another

element OSHA considers is the cost of those controls. We have developed a standard that covers the various aspects of controlling exposure and reducing risks without causing undue economic hardship on industry.

## ■ Robert Rosensteel

I will provide an overview of Title 3 of the recently enacted Clean Air Amendments that won't be directed at methylene chloride, specifically, as much as our overall Title 3 activities. Keep in mind how Title 3 might affect sources you're interested in, especially paint stripping and other processes that may be emitting any one of the 189 hazardous air pollutants on the Title 3 list. Methylene chloride is one of the pollutants in the list of 189.

A process is being developed that will allow the public to petition to add or delete pollutants from that list. EPA must make a determination within 18 months after it receives a petition. We are also required to publish a list of the major source categories emitting one or more of these 189 hazardous air pollutants. A major source is defined as "one that emits 10 tons per year or greater of an individual pollutant on the list or 25 tons per year or greater of multiple pollutants if the source is emitting more than one and that source is also defined as a contiguous area under common control." We are required to review and revise this list at least once every eight years. In addition, we must publish an emissions standards schedule for each of the source categories on this list. We plan to publish a draft list in May 1991 and allow a short, 30-day period for comments from the public about listed source categories. This list will be made final on November 15, 1991.

We can't tell you when a maximum achievable control technology (MACT) regulation emission standard will be established because we haven't developed Schedule I. In doing so, we will consider adverse effects on public health and the environment, the quantity and location of the category emissions, and the efficiency gained by grouping categories according to pollutants, processes, or technologies. Having done that, we are required by the amendments to promulgate regulations over a period of 10 years.

The initial requirement we're working on is to promulgate emissions for 41 source categories or subcategories within two years of enactment (November 1992). By the four-year mark, we must develop emissions standards for 25 percent of the listed categories; by the seven-year mark, 50 percent of the categories; and in 10 years, emissions

standards for 100 percent of the categories on the published list as of November 1991.

MACT requires development of emissions standards that would achieve the maximum emission reduction deemed achievable by EPA for new and existing sources in the category. The new twist to this authority is the minimum control level, or as we have been calling it within the program, the "floor" for new sources. A new source must be controlled at a level at least as stringent as the best-controlled similar source that is the "best of the best." There also is a minimum control floor for existing sources, which requires that they be controlled at a level at least as stringent as the average of the best 12 percent in the source category.

EPA's administrator then has discretion to consider emission standards that are more stringent than these floors, and, in doing so, may distinguish among classes, types, and sizes of sources within a category to determine how stringent those rules should be. There are general MACT emissions standards that are currently being developed.

One rule will affect the synthetic organic chemical manufacturing industry's relatively high volume petrochemical processes. If you are manufacturing what I call a "sock me" chemical and using an organic pollutant on the list of 189, then you are affected by this rule. There tends to be confusion about this: the rule pertains to the manufacture of a chemical, not the use of a chemical. The production of methylene chloride will be affected by this rule; however, the use of methylene chloride in paint stripping would not. We're also working on a comprehensive revision to asbestos rules and standards for chromium electroplating and commercial sterilizers.

In addition, we are assessing petroleum refineries and manufacturers of iron and steel and wood furniture. Pulp and paper mills are being studied by numerous offices within EPA, which are cooperating to produce new regulations.

The MACT compliance schedule normally requires that, once a rule has been promulgated EPA has up to three years to bring the sources into compliance. There is a provision for one-year extensions either by EPA or the state, if it has an approved permanent program. Another provision is early reduction; if a company achieves 90 percent early source reduction, then it gets a six-year extension from the MACT promulgation date. It can also get an extension of five years to comply with the MACT regulation if it has installed best available control technology before the rule goes into effect.

After having applied these MACT rules, EPA must consider residual risks. After we promulgate the standards, then we determine if there is an ample margin of safety to protect public health or prevent adverse environmental effects. For pollutants classified as "known," "probable," or "possible" human carcinogens, if the maximum exposed individual has more than a one-in-a-million risk, then we are required to set a more stringent emissions standard for that source category within eight years of the development of the MACT regulation, and for the two-year standards, within nine years.

One other provision concerns modification. Companies are modified if they increase emissions of hazardous air pollutants or have started using a hazardous air pollutant and are emitting it. In this case, if a company has reduced a more toxic pollutant on the list of 189, you can offset the increase in emissions of the less toxic one.

**Question:** What does NESHAP stand for, and why are surface coatings at the bottom of the list?

**Bob Rosensteel:** NESHAP stands for National Emissions Standards for Hazardous Air Pollutants. The list is in no particular order; those are all active projects.

**Question:** I believe consumer education is the key to success for the whole solvent replacement program. With regard to the consumer paint stripping applications and the new warning on the label associated with the use of methylene chloride, I'd like to know if EPA has taken a survey to determine whether the consumer reads the warning on the label. If customers do read the label, how much do they understand about methylene chloride, and if they don't, what is EPA doing in conjunction with OSHA to educate the consumer?

**Sandra Eberle:** The consumer-use applications of methylene chloride and the consumer education programs to encourage safer use of any products that contain it are the responsibility of the CPSC. CPSC, in cooperation with the industry, has been actively advising the public of steps to take, both encouraging people to read the label and using other means to get out additional information.

In addition, we have a survey at OMB that will ask consumers if they read the label and then measure their understanding of it. To some degree, we should be able to elicit whether or not they understand the hazard and are taking the risk anyway or are not informed and therefore not acting to reduce the risk.

# OECD Activities Overview—Panel

**Mary Ellen Weber, Moderator\***

*Office of Toxic Substances  
U.S. Environmental Protection Agency*

## ***The Canadian Approach to Regulating Paint Strippers***

**George Long**

*Department of National Health and Welfare  
Ottawa, Canada*

**I**n Canada, paint strippers are assessed both as consumer products and industrial products.

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### **Consumer Products**

Chemicals contained in them are mainly governed under Schedule I of the Hazardous Products Act, which is administered by Consumer and Corporate Affairs Canada (CCAC), with the Department of National Health and Welfare providing advice in matters of human health.

Under the Hazardous Products Act, dangerous chemical products may be controlled in several ways:

- An outright ban,
- Regulations imposing safety requirements,
- Requirements for special packaging, such as child-resistant closures, and
- Precautionary labeling and adequate directions for use.

Regulations pertaining to paint removers are found in the Consumer Chemicals and Containers Regulations of the Act, which govern their advertising, sale, and importation. To be regulated under the Act, a paint remover must contain specific concentrations of named chemicals.

Depending upon the product formulation, the Regulations specify precautionary labeling, which includes a hazard symbol, a hazard statement, and first aid statements. Precautionary labeling is

required for paint removers containing specified amounts of such regulated chemicals as methanol or toluene. However, methylene chloride is not regulated under Schedule I of the Hazardous Products Act.

In 1985, Consumer and Corporate Affairs Canada released an information bulletin—"Health Hazard Posed by Paint Strippers and Spray Paints"—in response to public concern over:

- Reports that methylene chloride proved carcinogenic to laboratory animals, and
- The increased risk of methylene chloride exposure for people with circulatory problems or heart conditions.

In the information bulletin, CCAC advised consumers to use paint strippers in a well-ventilated area.

In 1988, concern over paint strippers containing methylene chloride prompted CCAC and the Department of National Health and Welfare to initiate a review of this issue.

With the Department of National Health and Welfare providing advice on the potential human health effects of acute and chronic exposure to methylene chloride, CCAC examined the issue in terms of costs and benefits. CCAC also considered the question of alternatives to methylene chloride-containing paint strippers, including sanding, heat-stripping, and professional stripping, along with attendant problems such as volatilization of lead.

Concurrently, CCAC initiated a major review of its regulatory system for consumer chemicals

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\*Bo Wahlström, Chair, National Chemicals Inspectorate, Sweden, was unable to attend due to the Persian Gulf situation.

and decided to move from an ad hoc system to one that is criteria-based. As a result, no decision on the regulation of methylene chloride will be made until the new system is in place.

Presently, consumers are advised to use methylene chloride-containing paint strippers in a well-ventilated area, defined as "one in which the odour of the chemical cannot be detected."

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## Industrial Products

The Hazardous Products Act has provisions for industrial products under Schedule II. In Canada, paint strippers used in occupational settings are subject to the Controlled Products Regulations. In addition, the Workplace Hazardous Materials Information System (WHMIS) was established under a combination of federal and provincial laws. The legislative bases to enable its implementation are the Hazardous Products Act, the Canada Labour Code, the Hazardous Materials Information Review Act, and provincial occupational health and safety acts.

WHMIS provides Canadian workers with uniform safety information about chemical products in the workplace. The system's three key elements are:

1. Labels, with symbols, on hazardous material containers,
2. Material safety data sheets, and
3. Worker education programs.

Products are classified by a criteria-driven system. If a product meets the criteria as a controlled product, all hazardous ingredients must be disclosed unless an exemption is granted through a provision for product trade secrets. Methylene

chloride is on the Ingredient Disclosure List, which means that it must be identified on the material safety data sheet of a controlled product if it is present in a concentration of 0.1 percent or greater.

Under the WHMIS criteria, both the acute and chronic effects of a chemical must be declared. Methylene chloride, classified as an acutely toxic substance, also meets the criteria as a potential carcinogen because it is classified by the International Agency for Research on Cancer as a Group 2B carcinogen.

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# OECD Activities Overview—Panel (continued)

## ***Regulation of Methylene Chloride in the United Kingdom***

**Bill Holmes**

*Health and Safety Executive  
Technology Division  
Bootle, Merseyside, United Kingdom*

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### **Regulation of Hazardous Substances in the United Kingdom**

The United Kingdom Health and Safety Commission (HSC) and Health and Safety Executive (HSE) are bodies created by the Health and Safety at Work Act of 1974. The HSC is responsible for the administration of the act. In particular, its duties include taking appropriate steps to secure the health, safety, and welfare of persons at work and to protect the public against risks to health and safety arising out of work activities. The commission also commissions and sponsors research, promotes training, and provides an information and advisory service. The HSC is made up of eight representatives of trade unions, employers, and local authorities, and a ninth member appointed by the Secretary of State for Employment to represent wider consumer and public interests. A full-time chairman is appointed by the Secretary of State.

The HSE is responsible for day-to-day enforcement of health and safety legislation and contains divisions dealing with policy, inspection, scientific, medical, and technical activities. The legislation dealing with exposure to toxic chemicals in the United Kingdom is the Control of Substances Hazardous to Health Regulations 1988 (COSHH). This law is a comprehensive set of regulations requiring, among other things, that employers assess the risks to health arising from work with hazardous substances and apply appropriate control

measures. A hierarchy of controls includes elimination, substitution, enclosure, local exhaust ventilation, systems of work, maintenance, and general ventilation monitoring.

In setting standards for hazardous substances, the Health and Safety Commission makes substantial use of the Advisory Committee on Toxic Substances (ACTS). This committee comprises persons nominated by industry and trade unions, together with independent experts. ACTS is advised on occupational exposure limits for particular substances by the Working Group for the Assessment of Toxic Chemicals (WATCH), a tripartite group of experts. Data on the toxicity, production, uses, exposure, control, and sampling of individual substances are collected and analyzed by HSE staff for WATCH to review. WATCH then makes appropriate recommendations to ACTS. Wide consultation is carried out on the proposals before the limits are subsequently incorporated into the legislation.

Two types of occupational exposure limit (OEL) can be established under the COSHH regulations: occupational exposure standard (OES) and maximum exposure limit (MEL).

An OES is proposed if: (1) a "no effect level" for repeated exposure can be identified; (2) exposure to concentrations greater than the OES for the time it might take to identify and remedy the cause of the excessive exposure is unlikely to produce short- or long-term serious effects; and (3) the OES can reasonably be complied with.

A MEL is proposed if: (1) a substance is not able to satisfy the OES criteria and is liable to pose

a serious risk to humans (acute toxicity and/or potential to cause serious long-term health effects); or (2) socioeconomic factors indicate that, although the substance meets the criteria for an OES, a numerically higher value is necessary if certain uses are to be reasonably practicable.

Where a substance has an OES, compliance is achieved if exposure by inhalation is controlled to the specified level, or, where the OES is exceeded, the employer identifies the reasons and takes appropriate remedial action as soon as is reasonably practicable.

If a MEL has been established for a substance, exposure must be reduced to a level as low as reasonably practicable and must not exceed the MEL.

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## Policy Regarding Methylene Chloride

Methylene chloride is currently assigned a MEL of 100 ppm (8-hour time weighted average). The United Kingdom considers that exposure at this level is unlikely to produce harmful effects on man. The substance is assigned a MEL in view of the rapid increase in central nervous system effects with greater concentrations and the potentially serious consequences where exposure might exceed a few hundred ppm pending implementation of improved control measures.

In the European Community (EC), a Directive has recently classified methylene chloride as a category 3 carcinogen (i.e., possible irreversible effects) with consequent additional labeling requirements. The United Kingdom did not support the proposal but will, of course, implement the directive.

ACTS/WATCH reviewed all available data and concluded that, although the risk of carcinogenic effects could not be entirely discounted, the carcinogenic effects observed in animal studies ap-

pear to be of doubtful relevance to humans. In particular, major studies carried out by the European Chemical Industry Ecology and Toxicology Centre (ECETOC) highlighted the different metabolism of methylene chloride in animal species. It was on this basis that the United Kingdom opposed the EC proposal for classification as a Category 3 carcinogen.

Methylene chloride is a very effective paint stripper that HSE believes to be controllable and relatively safe for the environment. Replacement with substances about which there is insufficient information and which may introduce other risks is questionable. The HSE view is that hazards and risks should be closely evaluated and a decision based on relative risk assessments.

The main industrial problem involving methylene chloride in the United Kingdom is furniture stripping, which is usually carried out in small premises with few employees. High exposures have been found in this sector and have proved difficult to control. HSE believes that properly designed, installed, and maintained control equipment, suitable work systems, and good housekeeping are key factors in solving the problem. A Specialist Inspector Report on paint stripping to provide details on exposure levels and practical control measures is being prepared by the Occupational Hygiene Unit of HSE's Technology Division. This publication will be available to the public without charge.

The United Kingdom's view on methylene chloride evolved from a broad base of science and experience and is endorsed by independent committees, toxicological experts, and academics. Our system is "open" and receives great cooperation from all sectors of industry. We believe that the HSE position should receive serious consideration from other countries facing the trade-offs involved in making sensitive decisions regarding the regulation of chemicals and the environment.

# OECD Activities Overview—Panel (continued)

## **OECD Risk Reduction Activities: A Process for Cooperative Work on Specific Chemicals**

**Victor Morgenroth**

*Organization for Economic Cooperation and Development  
Paris, France*

**I**n March 1990, the Organization for Economic Cooperation and Development (OECD) held an ad hoc meeting of experts in Stockholm to explore a new approach to managing chemicals. This meeting discussed the so-called "sunset" initiative, whereby the use of chemicals with risks considered incompatible with sustainable development would be phased out either totally or for certain uses as safer acceptable alternatives become available, and recommended that it be included within the wider concept of risk reduction.

To incorporate the sunset initiative, measured responses to deal with unacceptable risks must be developed through application of various instruments appropriate to both the nature and extent of the risk. These responses would encompass both regulatory and nonregulatory measures as well as economic instruments and could include:

- Cleaner products and technologies.
- Emission inventories.
- Labeling.
- Citizen and consumer guides.
- Training materials.
- Product Stewardship commitments.
- Recommended disposal or recycling practices.
- Use limitations, and
- Phaseout or banning of chemicals for certain, specific uses.

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### **Risk Reduction of Specific Chemicals**

At their 14th joint meeting, the Chemicals Group and Management Committee of the OECD Special Programme on the Control of Chemicals agreed that new risk reduction activities should be started with a pilot project on the risk reduction of specific chemicals. A lead country approach within the framework of the cooperative work on existing chemicals was chosen as the most appropriate way to initiate this work.

The lead countries that agreed to be responsible for specific chemicals were:

- The Commission of the European Communities (for cadmium, Sweden as co-sponsor).
- The United States (for lead, Denmark as co-sponsor).
- The Nordic countries (for mercury).
- The Netherlands (for brominated flame retardants), and
- Sweden (for methylene chloride, Switzerland as co-sponsor).

### **Preparation of Analyses of Risk Reduction Possibilities**

Each lead country has prepared a draft analysis of the possibilities for risk reduction that includes:

- A rationale for initiating the study.

- A brief summary of current hazard and/or risk assessments. (It is well documented that certain of the selected chemicals, mercury, lead, cadmium, and methylene chloride are potentially harmful to health and/or the environment. These compounds as well as brominated flame retardants have been or are being reviewed by the United Nations International Programme on Chemical Safety, which has prepared comprehensive, peer-reviewed hazard assessments.)
- An analysis of the various uses, sources, pathways, and environmental fate of the chemical(s), including commercial and environment life cycles and mass flow analysis.
- Possibilities for, or estimates of, exposure from each of the significant uses.
- Identification of the extent or degree to which certain uses are essential.
- The availability of substitutes (chemicals and/or technologies) in the foreseeable future.
- Suggestions for regulatory, nonregulatory, and economic instruments to achieve meaningful risk reductions.
- Possible strategies for risk reduction at both the national and, as appropriate, the international level.

Other member countries assisted the lead and co-sponsor countries by submitting information on the selected chemicals that included

- Summaries of new data on the hazards or risks of the chemical;
- Information on use categories, production volumes, and
- Environmental and/or commercial life cycles; possible substitutes and/or control technologies, and existing or planned regulations or risk-reduction measures.

In November 1990, the lead countries submitted the first drafts of executive summaries and analyses to the other member countries. The Joint Meeting determined that these documents were of value and that, once finalized, should be considered for derestriction to make them widely available. It also agreed that draft reports should

be broadened, peer-reviewed, and finalized through a value-added commenting process, open to all member countries and all sections involved, that would lead to consensus building, improve the consistency, and ensure high quality results. Member countries using or considering different approaches to risk reduction of the five subject chemicals or groups of chemicals than those already discussed or covered in the reports will describe their experiences.

### **Consultation Process**

Early comments have emphasized the need for including an analysis of the economic effects of certain suggested risk reduction measures; more extensive consideration of the need for and availability of substitutions—particularly where a phasing out is suggested (including commentary on the adequacy of substitute assignments; and a crisper presentation of certain aspects of risk assessment that lead to specific suggestions for risk reductions.

Once the comments of member countries have been incorporated, the documents will be considered for derestriction as discussion documents so that all sectors including labor, industry, and various nongovernmental organizations can have an opportunity to comment on the substance and the recommendations included in the reports. Subsequent to that consensus-building process, they will be considered for publication as OECD documents. This process should be completed by the end of 1991 or sometime in early 1992. The final reports would also serve as a basis for decisions on the future direction of risk-reduction activities.

### **The New OECD Council Act on Existing Chemicals**

As work began on risk reductions of specific chemicals, the Joint Meeting endorsed a more general policy statement. This was incorporated in an OECD Council Act on the Co-operative Investigation and Risk Reduction of Existing Chemicals, which was considered by environment ministers and adopted by the Council in January 1991. The ministers discussed risk reduction as a general policy issue and the opportunity to make a commitment to risk reduction on a cooperative basis.

It should be emphasized that the pilot project on risk reduction was not advanced enough for ministerial decisions on specific chemicals.

# Labor's View on Reducing Risk in Paint Stripping

**John B. Moran**

*Occupational Safety & Health*

*Laborers' Health and Safety Fund of North America*

*Washington, D.C.*

**T**his conference is unique in three important and significant aspects. First, most of the use areas involve one common receptor: workers. Second, the conference's topics are all on well-recognized, basic industrial hygiene approaches to reducing exposures to workers. Third, and most importantly, with the sole exception of this presentation, labor is not represented. Frequently, labor's role as a stakeholder has not been recognized in meetings such as this conference. Perhaps this occurs because some businesses think that labor either cannot or should not participate. Another aspect of this conference should be recognized: the sponsor is the U.S. Environmental Protection Agency (EPA), while the responsibility for worker protection rests with the Occupational Safety and Health Administration.

It is heartening to see EPA becoming—through the Toxic Substances Control and Resource Conservation and Recovery acts and other legislative mandates—more actively involved in areas important to worker protection. During the past months,

EPA has embraced labor as a stakeholder in these matters by creating the special task force to focus on worker protection issues at Superfund sites, inviting active labor participation in the HUD/EPA lead-based paint task force, and appointing one labor representative to the 27-member, negotiated rulemaking panel for lead-acid battery recycling regulations.

We are encouraged and commend EPA for expanding its horizons on these important issues to include those most directly impacted: the workers. We can, have, and will seek to continue to be informed contributors.

Labor is an important constituency that is directly impacted in every step of the Toxic Substances Control Act cradle-to-grave route. Since workers are—all too often—the first and worst exposed, our contributions can be important to overall national efforts to reduce or eliminate human risk associated with exposure to hazardous materials or substances.

# Product Stewardship—Panel

**Paul Cammer, Chair**

*Halogenated Solvents Industry Alliance*

## ***Product Stewardship and Chemaware at Dow***

**William C. Hayes**

*Chemicals & Metals Department*

*Dow Chemical Company*

*Midland, Michigan*

**T**oday I will briefly describe Dow's product stewardship program, and then provide some specific examples of Dow's product stewardship efforts in the area of paint stripping.

At Dow, we believe that product stewardship is an investment in the future. In fact, stewardship and concern for the environment are part of the company's core values. Our product stewardship philosophy includes obtaining and assessing health and environmental information; evaluating customer use; and taking appropriate steps to protect employees, the public health, and the environment. In short, we have made a commitment to do what's right.

The program has five purposes:

- Protect employees, the public health, and the environment;
- Protect our products from the environment;
- Help reduce liability;
- Help prevent adverse publicity; and
- Increase customer involvement and business.

Dow's product stewardship program is not new; it began more than 60 years ago. Examples of Dow's product stewardship activities follow:

- 1930—First monitored plant effluent.
- 1933—Established toxicology laboratory.
- 1946—Opened first rotary kiln for wastes.
- 1950—Conducted first industrial hygiene survey for customers.

- 1958—Developed first material safety data sheets.
- 1969—Formed corporate ecology council.
- 1972—Formally defined product stewardship.
- 1977—Held first product stewardship workshop.
- 1987—Launched Chemaware program.

The responsibility for product stewardship is not confined to any one person or group. The responsibility for product stewardship is shared by many company functions, including Research and Development, Manufacturing, Distribution, and Marketing. The Research and Development function obtains data, develops acceptable applications, and provides information. Manufacturing informs employees, assures a healthy work environment, and adheres to pollution control and industrial hygiene standards and guidelines. Distribution selects carriers, warehouses, and terminals to perform according to Dow's guidelines. And Marketing furnishes customers and distributors with appropriate information, informing them about known use limitations.

The product steward for a specific product or chemical is typically in Technical Service and Development (TS&D). The functions of the product steward include assessing appropriate uses of the product or chemical, assisting sales personnel, evaluating customer use and disposal practices, preparing training tools, recommending needed health and environmental studies, and interacting with governmental agencies.

In response to a need for greater, more visible product stewardship, we have developed Chemaware.<sup>®</sup> Chemaware is the Chemicals and Metals Department's enhanced product and environmental stewardship program designed to assist users of our products with handling, storage, recycling, disposal, and safety procedures. The Chemaware stewardship program:

- Increases awareness of proper stewardship;
- Documents product stewardship efforts;
- Minimizes product liability;
- Reduces need for additional regulation; and
- Places the company in a leadership role for product stewardship.

Elements of our Chemaware program that are available to our distributors and customers include services designed specifically for chlorinated solvents:

- Training aids and videos;
- A product stewardship manual;
- Technical literature; and
- Distributor training and environmental seminars.

Additional services that are available at the discretion of TS&D include:

- Field support;
- Laboratory and analytical support;
- Vapor monitoring;
- Environmental and regulatory services; and
- Solvent conservation and emissions recovery.

There are materials and services available for methylene chloride and, more specifically, for paint stripping. Our basic materials include the solvent stewardship manual, a Chemaware kit for methylene chloride, and a videotape on how to handle methylene chloride safely. The video is available for viewing through Dow Field Sales and TS&D.

Our efforts in paint stripping are obviously more focused. For example, at the Halogenated Solvents Industry Alliance, we created a point-of-

purchase brochure on the safe way to strip paint from wood. More than 100,000 copies of this brochure have been sent to distributors and formulators for further distribution to the customers. In addition, over 65,000 copies have been distributed by the Consumer Information Center in Pueblo, Colorado.

In 1990, we also developed a short feature article on the safe use of methylene chloride. The article was distributed to over 7,000 suburban newspapers with a projected circulation of 23 million readers. Throughout 1989, a radio public service announcement was aired on 265 radio stations reaching an estimated 15 million listeners in 46 states. A similar project is planned for this year. We also are working with the producer of public television's "This Old House" to include a segment on paint stripping in 1991. Our goal is to have safe handling information included on any program that involves the use of methylene chloride paint strippers. For the industrial paint stripping segment, we plan to develop a safe handling video in 1991.

Finally, we have placed articles on the safe use of methylene chloride paint strippers in industry-specific journals. Articles published since 1988 include:

- 1988. Methylene chloride: balancing health with safe handling. *American Paint & Coatings Journal*.
- 1988. Safe handling urged with methylene chloride. *American Painting Contractor*.
- 1989. Safe use of methylene chloride. *Occupational Hazards*.
- 1989. Methylene chloride for furniture stripping: effective and safe if handled with care. *American Painting Contractor*.
- 1991. Methylene chloride paint strippers. *Old-House Journal*.

We will continue to seek opportunities to educate the public and the worker.

In closing, Dow has a three-part commitment to product stewardship:

- To ensure the safe manufacture, distribution, and use of Dow products;
- To do what we know is right; and
- To provide this information and service to help our customers do the same.

# Product Stewardship—Panel (continued)

## Controlling Paint Stripping Emissions

**W. Piatkiewicz**

*ICI Chemicals and Polymers  
Runcorn, Cheshire, United Kingdom*

**I**deally, a paint stripper should be effective in formulations with all paint types, have an acceptable toxicological profile, and be an environmentally safe product. However, no matter how well they fulfill these goals, all paint strippers produce emissions in the workplace.

Four approaches should be taken to reduce these emissions:

- Change the formulations
- Install more-suitable equipment
- Use better working practices and
- Provide adequate ventilation.

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### Formulations

The following table shows the effect of different formulations on emissions.

**Table 1.—Effect of formulation on emissions.**

	EQUIL CONC (ppm)	MAX (ppm)	TIME TO REGAIN EQUILIBRIUM
M.E.	3,000	5,500	70 secs.
Formulation "A"	7	5,600	5 min. 50 secs.
Formulation "B"	15	6,000	5 min.
Formulation "C"	15	6,000	4 min. 40 secs.
Formulation "D"	17	5,200	4 min. 30 secs.
Formulation "E"	7	5,400	3 min. 20 secs.

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### Equipment

A good solution for controlling emissions is to capture the vapors at the source. When stripping paint, this can be done by using a lid or a perimeter slot around the rim of one side of the tank (or storage vessel), and a corresponding air input slot

on the opposite side of the tank, preferably along the major axis. Figure 1 depicts a paint stripper bath with a manual rolling shutter lid; Figure 2 gives an idea of the proportions of a paint stripper tank that is equipped with both a lid and rim ventilation.

These recommendations are derived from the metal cleaning industry's use of chlorinated solvents and have been shown to effectively achieve compliance to occupational exposure limits. It is only sensible to extend these practices to paint stripping.

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### Working Practices

Employees can reduce emissions by using better handling practices.

The rate of removal of material from a stripping bath should be a maximum of 10 feet per minute with a vertical lift. During 2,000 annual working hours, drag-out, idling (idling plant set for operation), and standing (plant not operating, lid off tank) losses of emissions each usually total 30 percent; clean-out losses encompass the remaining 10 percent. However, because drag-out losses depend on the amount of work done, they can range from 30 to 65 percent of operating losses.

Controlling drag-out losses will substantially reduce emissions into the workplace and, by using the basic design parameters shown in constructing a stripping bath, together with a lid, will reduce further losses to the atmosphere.

The further reduction of emissions and therefore user exposure can be achieved by modified formulations. As shown, these formulations differ

MANUAL ROLLER SHUTTER LID

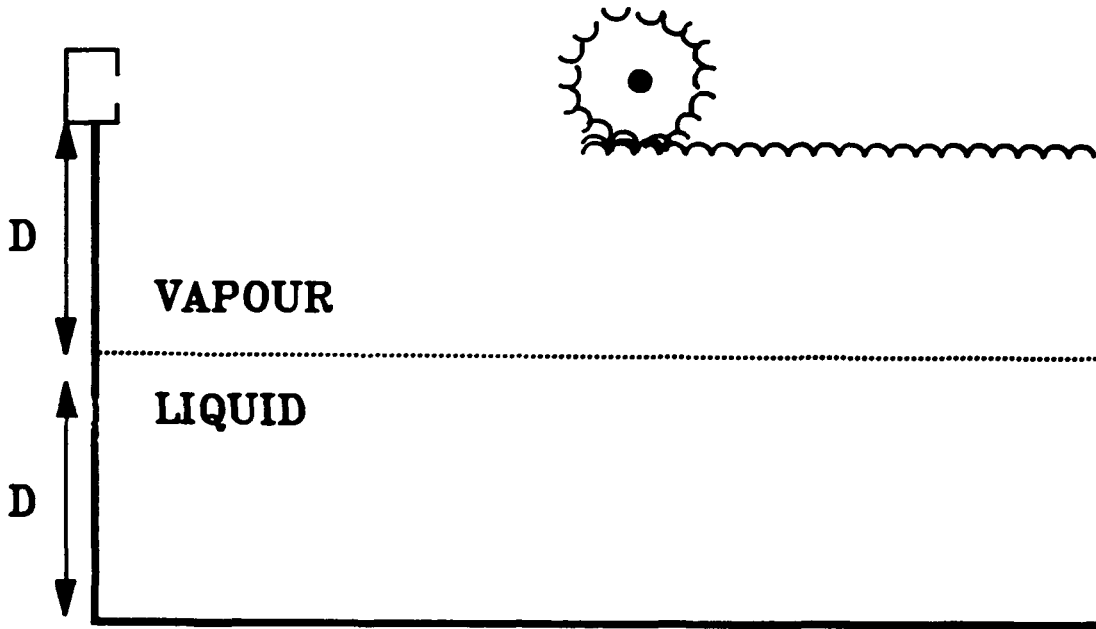


Figure 1.—Roller shutter for paint stripping bath.

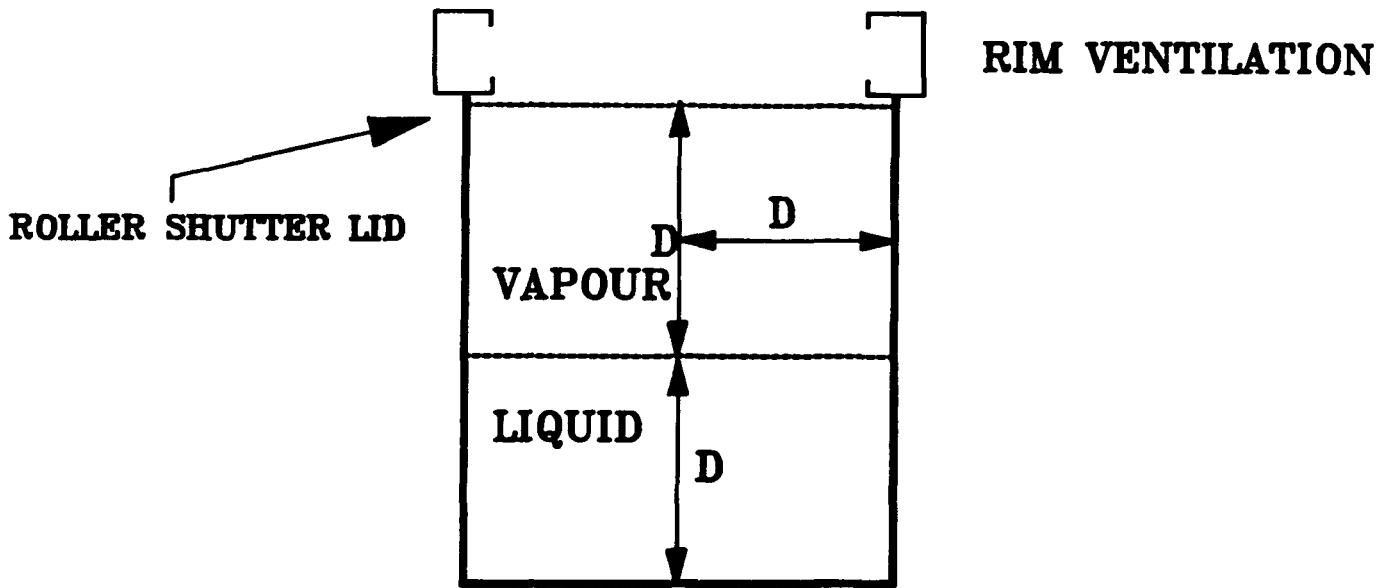


Figure 2.—Proportions of paint stripper bath.

substantially in their ability to self-skin and contain the evaporation of the paint stripper.

**Ventilation**

Where emissions are controlled solely by space ventilation without using canopies or other methods, the following should be considered:

- The air change rate should be 40 to 60 percent per hour, and

- The enclosure volume should be reduced as much as possible. This can be achieved by enclosing the process in a PVC-type of curtain in a dedicated room or separate building.

The flow of air through the building should be turbulent. The fans extracting polluted air should be placed opposite vents emitting fresh air. Figure 3 diagrams bad, fair, and good air distribution with air fans.

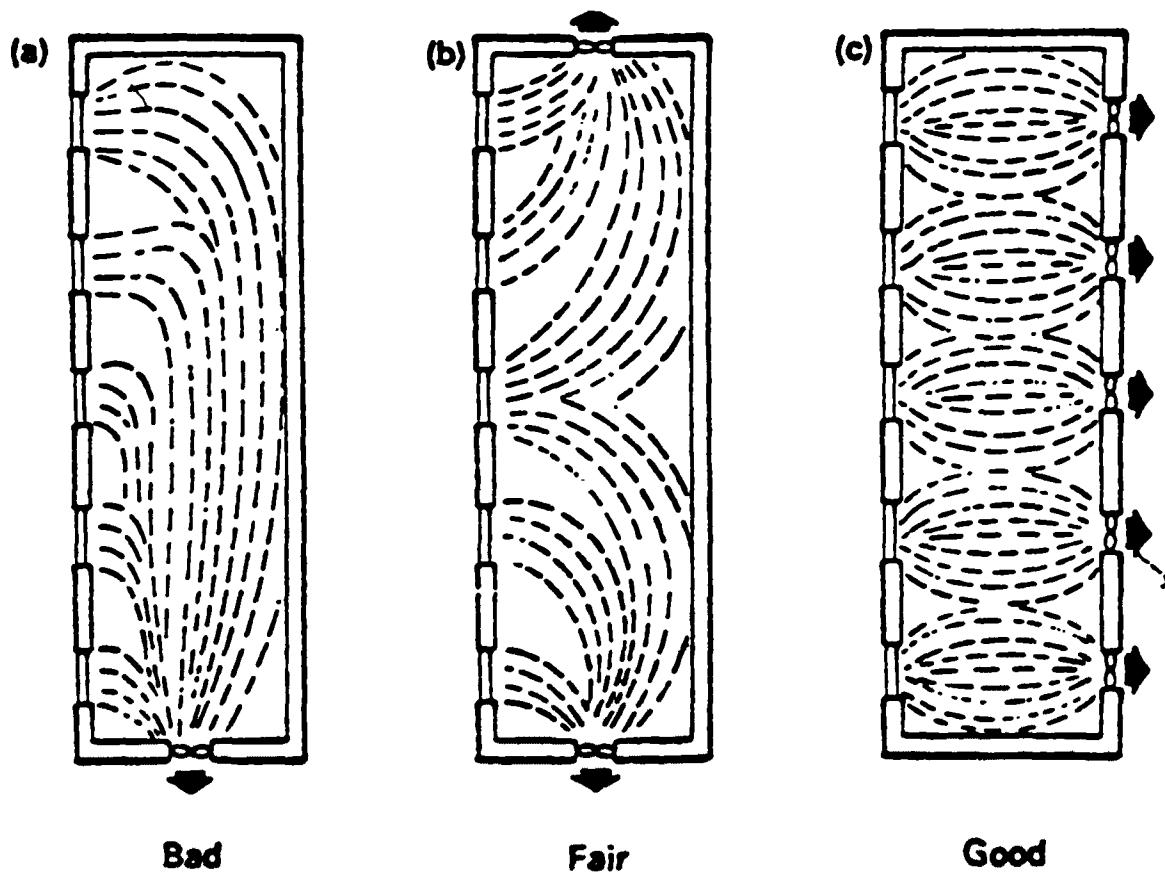


Figure 3.—Good, fair, and bad distribution with wall fans.

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## Summary

The simple techniques outlined in this presentation show much can be done to reduce emissions of methylene chloride and, hence, worker and user exposure.

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# **ORIGINAL EQUIPMENT MANUFACTURING**

## ***Current Paint Stripping Practices***

**Chair:** Christine Whittaker  
*Office of Risk Reduction Technology  
Health Standards Division  
U.S. Occupational Safety and Health Administration*

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# Pollution Prevention Case Study: Methylene Chloride Substitution in an Automotive Plant

**Jack Davis**

**William Reichert**

*Sanitation Truck & Bus Group*

*Flint Bus Assembly Plant*

*General Motors Corporation*

*Flint, Michigan*

**T**he purpose of my presentation this afternoon is to describe (1) the activities that involved the use of methylene chloride strippers at the Flint Truck Assembly Plant in the early 1980s, and (2) the substitute products (and operational changes) that we have implemented since then to replace methylene chloride. I will explain not only the benefits of the switch from methylene chloride, but also some of the compromises that we have had to make.

Our plant is part of the General Motors (GM) Van Slyke Road Complex. The complex consists of three separate plants: the Truck & Bus, Flint Metal Fabrication Plant (which produces sheetmetal stampings, frame parts, and miscellaneous metal components); the GM Power Train Division, Flint V-8 Engine Plant (which assembles V-8 engines and includes machining associated with this activity); and finally, the Truck & Bus Assembly Plant.

At Truck & Bus we presently produce Blazer and Suburban vehicles on two separate lines, and Crew Cab vehicles. Since it opened in 1947, the plant has operated two lines for most of its existence.

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## Assembly Plant Operations

The assembly plant operations consist of three distinct processes: welding, painting, and assembly.

- **Welding** consists largely of spot and mig welding of sheetmetal panels.

### ■ **Painting** includes:

- Washing the metal parts;
- Treating the bare metal parts (phosphate and chromic rinses);
- Applying a prime coat of paint (Elpo Dip Process); and
- Applying topcoat paint to vehicle surfaces (base coat, clear coat).

### ■ **Assembly** includes:

- Installing the interior trim seats, electrical wiring, and so forth, in the painted vehicle bodies;
- Assembling the frame components, including the frame rails, springs, axles, transmission, engine, and so forth; and
- "Putting it all together"—assembling the body to the completed chassis, then adding the remaining components.

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## Maintenance Operations

In addition to production, methylene chloride has also been used in maintenance. The following information is primarily from our response to a 1987 U.S. Environmental Protection Agency (EPA) questionnaire created to gather information from both industrial and commercial users of methylene chloride-based strippers.

The advantages of using methylene chloride were many and varied:

- **Low flammability**, making it ideal for use in highly hazardous locations such as the paint mix room and spray booths.
- **Fast "cold stripping,"** able to lift uncured paint almost immediately and cured (oven baked) in a matter of minutes.
- **Excellent stripping qualities**—definitely the best cold stripper. It could be used on virtually any paint or surface, and required very minimal scraping.
- **Water solubility**, making it very easy to rinse off both the stripped material and the stripper itself.
- **Few skin or eye hazards** when compared with caustic materials such as sodium hydroxide.
- **Easy application**—just lay it on and scrape it up.
- **Relatively low odor and fumes**, with less chance of asphyxiation compared with other chlorinated strippers. These attributes made methylene chloride the wonder product for paint shop maintenance during the 1980s.

This material was the primary cleaning/stripping agent for three main areas at Flint Assembly:

- Internal maintenance of the paint spray booths;
- Interior stripping of the paint supply lines located between the mix rooms and the paint spray booths; and
- Concrete floor stripping prior to installation of protective coatings.

Every day during actual production, paint over-spray was stripped from the interior of spray booths and equipment. In this operation the stripper was applied to the walls, floors, and ceilings, allowed to set, and then rinsed off with water. At this point, the paint is uncured and sticks to virtually every surface it touches.

During this period the plant was running two shifts per day, leaving very little time for cleaning up. Therefore, a product was needed that could be:

- Easily applied (methylene chloride could be sprayed on the surfaces);
- Relied upon to lift the paint quickly; and

- Quickly rinsed off into the booth water below (because it was miscible in water, methylene chloride was ideal for this).

Daily cleanups were required when high-solids enamel paints were substituted for lacquers to meet air quality standards at Truck & Bus Flint. Enamels, while better environmentally, left surfaces sticky. Methylene chloride was introduced at the time (early 1980s) we switched to high-solids enamels, and presented a quick and complete solution to the new problems associated with this paint.

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## Search for Alternatives

The EPA regulation controlling total toxic organics (TTOs)—solvents—in the wastewater stream spurred us to replace methylene chloride. As part of the pretreatment requirements for industrial wastewater prior to its discharge into the City of Flint's municipal wastewater treatment plant, a very low total TTO limitation was placed on our wastewater stream. One of the solvents on the TTO list was methylene chloride. We had to find a substitute for methylene chloride that retained many of its advantages.

Fortunately, paint overspray in the booth is uncured, making it easier to find a solution. Unfortunately, we still have not found a comparable cold stripper for baked or cured paint.

The TTO problems, combined with impending legislation on restricting methylene chloride use, motivated chemical manufacturers to develop alternatives. At Truck & Bus, we tried a number of these substitutes, none of which worked as well as methylene chloride *in terms of stripping time*. We eventually settled on CLM 818. While CLM 818 does the job, it does have a few drawbacks.

- The material is slower than methylene chloride. Note that no mention of time is included in the ad.
- This product *must be washed off with water*. The evaporation rate is slower, and in fact, the materials will leave gel residues if not rinsed off completely. The rinsing process affected our paint purge solvent collection systems, and forced us to install special drains in collection pans to allow cleaning during the third shift. Regular tie-in to the purge collection system is available during actual production during the first or second shift.

- Both methylene chloride and the alternative product are not compatible with topcoat paints; however, the alternative cannot be used during actual production hours. Methylene chloride did not present as much of a problem because of its higher evaporation rate.

Actually, CLM 818 was not the first product we used, and is one of two we are presently using. (An earlier version of CLM 818—called CLM 320—required constant agitation to prevent settling in its tote tank.) CLM 818 is presently used in the Blazer-Suburban paint booths, while a Chemfil product, PPG Chemfil Polystrip #3450 (recently replaced with #3480), is used on the Crew-Cab paint system booths. The difference between the Chemfil and CLM 818 is that the Chemfil product does not require the water rinse—the product itself is used for rinsing, and any residues evaporate. The disadvantage of this product was its odor. Because of employee complaints, a new #3480 has replaced #3450 (without the odor). If this product is successful, we may test it on the Blazer-Suburban system, eliminating contamination and water rinsing required in our solvent collection systems.

### Comparing the Alternatives

What is the principle behind these substitutes for methylene chloride—what do they contain? Although supplier confidentiality prevents exact descriptions, the primary ingredients for CLM are:

- Phenyl carbinol
- Aromatic hydrocarbon (naphtha)
- N-methyl pyrrolidone
- Trimethylbenzene

The Chemfil product is primarily diacetone alcohol.

Most methylene chloride substitutes contain solvents such as naphthas and alcohols. Also, glycol ether was a major constituent of some of the trial products. The products we presently use have lower amounts, if any, of these constituents.

The materials presently used also have other severe restrictions to formulation besides TTOs. Cleaning materials containing products such as toluene and methyl ethyl ketone could contaminate the booth water, making it a F-code hazardous waste under Resource Conservation and Recovery Act (RCRA) guidelines. This could make all of the plant's industrial wastewater an F-code waste.

With all of the chlorinated solvents eliminated by TTO restrictions and most other good solvents eliminated by RCRA, it really does require innovation to come up with an effective stripper.

In summary, for the first of our three prior uses of methylene chloride, we have found substitute products. We have sacrificed:

- **Speed**—the substitutes take longer to perform the same operation;
- **Possible water contamination**—some of the substitutes require greater rinsing;
- **Odor**—resulting in complaints from employees; and
- **Stripping ability**—the substitutes cannot strip baked or cured paint.

The second major stripping operation needing a substitute for methylene chloride was the interior of the piping used to transfer topcoat paint from the paint mix room to the spray booths. Paint is stored in large vats in a special explosion-proof room; from there it is transferred to spray booths. With 10 to 20 miles of piping, spraying approximately two to four gallons of paint per minute, recirculation to the mix rooms is required to prevent paint from settling out in the lines.

To maintain the quality of the finished trucks, a routine procedure was developed to remove paint, rust, and dirt from the interiors of the paint recirculation system. The same procedure was used to clean the system when removing an obsolete color.

The standard procedure, developed over many years, involved a nine-step cleaning process that included a methylene chloride stripping operation. Other steps involved the use of various paint solvents, as well as a caustic stripper, to ensure clean lines. The cleaning materials were added to the paint vat or tank, then circulated through the piping back to the tank, where contaminants were collected. Filters, installed on both the supply and return lines, ensure that these contaminants are trapped and collected when returned to the tank. Cleaning materials were collected and sent for reclamation.

Again, TTOs in the wastewater precipitated a change. Use of a caustic stripper following the methylene chloride step caused a chloride residue in the caustic solution. This chloride contamination in the waste stream presented a major treatment problem when the caustic sodium hydroxide, a water-based material, was sent to the wastewater treatment plant for processing. To eliminate

the contamination, we added another step—an alcohol rinse between the methylene chloride and the caustic steps. Alcohol was a non-TTO substance, so alcohol residues in the caustic stage did not present a problem.

While this helped, it really wasn't enough. The whole operation became too cumbersome; residual caustic material would be present in the next solvent rinse, which would contaminate the solvent to such an extent that it couldn't be reclaimed, resulting in a high disposal surcharge.

After investigating alternatives, we decided to use a product from Gage Company: S-585 One-Step Line Cleaner. This product:

- Contains no methylene chloride or caustic chemicals;
- Requires fewer steps, saving time as well as cost;
- Contains only solvents already used in topcoat paints (Xylene, etc.);
- Allows use of either total recycling or the Chem-fuel alternative for disposal; and
- Uses a grit or an abrasive substance to do the actual stripping, and a solvent to transport the abrasive material.

The abrasive stripper is currently used for paint line cleaning. The change was made last year; so far the new method seems to be equal in cleanliness to the nine-step process. However, we continue to consider other alternatives. For instance, we are preparing to evaluate the effectiveness of a "pipeline pig" system that is used by other GM facilities.

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## Stripping Floors

The final operation in which methylene chloride was used would probably be considered a more conventional use—stripping paint off concrete floors.

Throughout our plant, particularly in our paint shops, we have concrete flooring coated with urethane to ensure lasting wear. Keeping the paint shop floors very clean helps promote good paint quality, and is a major goal for the sanitation department. Similar floor conditions are necessary in other areas such as Audit, a highly visible final inspection area.

A regular routine was established for stripping and reapplying the urethane coating. A virtually

"new" floor was created each time, and the entire process completed in a weekend.

Methylene chloride-based products provided the only quick and efficient method of removing a urethane floor sealer from a large concrete floor area. The material could be poured on and pushed around with scrapers or squeegees. After setting, the lifted urethane could be squeegeed and broomed to a central location to be shoveled up. Only a minimum amount of scraping was necessary—the removal process would take only a couple of shifts on Saturday, and the new urethane could be applied on Sunday. Without methylene chloride, resurfacing an entire paint shop floor with urethane in a weekend was impossible.

Employee exposure was a concern in this operation. Personnel performing these operations were supplied with protective equipment, including respirators, gloves, aprons, boots, and hats. In spite of this high level of protection, we decided to find a substitute.

We experimented with various products to find something suitable. Two factors were involved:

- The material being stripped *was fully cured*, and therefore the stripping requirements were more demanding than in our other two applications.
- This was not a regular maintenance operation and we had more time for testing and evaluation—we just put off stripping the floors.

After many trials, we never found a chemical product to match the performance of methylene chloride. The products tested either:

- Didn't strip the floor material;
- Stripped the floor materials to some extent but required lengthy periods of time;
- Had handling problems, such as emitting terrible odors, were difficult to apply properly, required constant agitation, settled in the drums, were highly flammable—and still did only a borderline job of stripping.

What was our final answer for stripping floors? We are using two distinct solutions today:

- A switch in the product used to protect the floors from a urethane to a wax type of sealer; and

- A switch to mechanical floor stripping using scarifiers and application of a permanent epoxy coating.

The wax type of sealer contains the following ingredients: water (80 percent), Dowicil, leveling agent, Carbitol, ethylene glycol, nonionic surfactant, polyethylene emulsion, and acrylic emulsion polymer.

These materials have the following advantages:

- Much easier than urethane to strip—we can use a wax remover containing such chemicals as: d-Limonene, light caustic acid, phosphates, or substitutes described for the first operation—glycol ethers, alcohols, naphthas, or a combination thereof.
- Quick and easy to apply.
- Dry very quickly compared with urethane, allowing the floor surface to be back in service much faster.
- Lower odor levels and less flammable compared with the high solvent that contains urethane. This results in greater safety, fewer employee complaints, and less protective equipment required.

However, the material does have some disadvantages:

- It is not as durable and has to be replaced more often. Ease of removal makes it easier to wear off or be stripped off by regular use. Therefore, it has to be reapplied considerably more often.
- More product is needed to obtain adequate protection, resulting in higher purchase and labor costs.

- It does not provide the new look that the urethane provided. The surface does not have a high gloss.

Although more expensive, the epoxy coating provides a "permanent" surface. It consists of the following steps:

- Mechanically removing the floor coating using a powerful tennant scarifier, which also roughs up the concrete to allow super adhesion.
- Applying 1/4" to 3/8"-thick coating of super epoxy, leaving a surface which is virtually impenetrable, super smooth, and super glossy; one that can be maintained with mopping.

Epoxy offers a more permanent solution—the resulting surface is *extremely* durable, has a very glossy, clear appearance, and is very smooth and easy to clean. Epoxy, however, has several disadvantages:

- Requires much more preparation and time;
- A heavy duty scarifier must be used;
- Creates a considerable amount of dust; and, most importantly,
- Is *very, very expensive*, normally running from \$5 to \$10 per square foot, depending on the product.

We are currently using both of those methods in our plant. The Line #2 Paint Shop Floor Area has been largely resurfaced with the epoxy materials.

This is our story. We hope it helps you understand assembly plant requirements for methylene chloride in stripping operations. We have spent much time searching for and testing potential substitutes, and continue to search for more effective, less expensive solutions.

# An Overview of Paint Stripping Practices in the Metalforming Industries

**John F. Grainger**

*Turco Products, Inc.*

*A Division of Atochem North America*

*Westminster, California*

**V**irtually any industry that fabricates metal parts will have recurring need to salvage or rework rejected parts. Although most industries have embarked on programs to enhance quality and minimize bad production, rejects still occur. Since many if not most metal parts are coated with some type of organic coating, either functional or decorative, this reworking often involves removal, or stripping, of that coating. The decision to rework or scrap depends on the value added to the part in prior manufacturing steps plus the cost of reworking as opposed to the cost of disposal. Usually these economic considerations favor reworking.

Industrial paint stripper users span the gamut of manufacturers, from the automotive to the electronics industry. Included are such diverse products as typewriters, computers, oil rig equipment, earth moving equipment, aircraft ground equipment, military ordnance (including ammunition and bombs), large and small household appliances, office furniture, highway signs and signals, and even caskets.

Although each of these industries needs to strip rejected or reworked parts, they differ widely in the methods chosen to accomplish this. Several factors are used to evaluate and select these methods. First and foremost, of course, is cost. The added cost of stripping and refinishing rejects must be recoverable or at least be less than the cost of scrapping the part. Beyond that, the stripper must be safe on the substrate and for using and operating personnel, and it must be relatively economical to dispose of at the end of its useful life.

When such a product is identified, an in-house specification is often written based on that product. This tends to lock in place the product and the procedure. The overall effect of this is to delay if not discourage introduction of new and especially innovative products. Few department heads or supervisors seek out the dubious honor of being the first to prove that a new process will work. Unless the operation is disrupted or outside pressure, such as a new regulation, is brought to bear, most seem content to let well enough alone.

The basic technology of paint stripping is based almost entirely on empirical observation. The actual mechanisms of stripping are not well understood or firmly grounded in theory. Prediction is erratic at best, and most often, when a new part or paint is to be stripped, the most practical approach is to select a few strippers that have worked on similar parts or paint schedules in the past and evaluate their performance on the new part or new paint to be stripped.

In discussions of paint strippers or paint stripper technology, it is useful to categorize the many available strippers into groups and discuss each group as a whole. Strippers may be characterized by the type of paint they are meant to strip—epoxy strippers, lacquer strippers, etcetera—or by the method of application—thickened, spray-on strippers, hot tank immersion strippers, and so forth—or by their principal components. The last category is probably the most informative and will be the method of classification here. Generally, distinctions are clear cut, but occasionally an ambiguous case arises and classification is then based on secondary characteristics.

For this discussion, paint strippers will be divided into three broad categories:

- **Aqueous (water-based) strippers.** Water is the major liquid solvent present, although organic solvents may institute up to about 20 percent of the composition.
- **Solvent-based strippers.** Organic solvents are the major liquid components, although water may be up to about 35 percent of the composition.
- **Mixed or semi-aqueous strippers.** Appreciable amounts of both water and at least one liquid organic solvent are both present in amounts ranging from 40 to 60 percent.

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## Aqueous Strippers

Water-based or aqueous strippers include both caustic and acid products. The caustic strippers are the most widely used in this category.

Caustic strippers generally contain from 10 to 20 percent sodium hydroxide (or less frequently, potassium hydroxide). These are among the very oldest industrial paint strippers for metal parts. They generally include substantial amounts of caustic stable surface active agents (or surfactant), chelating agents, and up to 20 percent organic solvents. These additives are necessary to strip some of the more resistant paints. Caustic strippers in general are almost always used in an immersion process in which individual parts or baskets of parts are immersed in the solution until stripping is completed. These products are operated hot, at temperatures ranging from 180°F to 240°F. The aqueous products usually work by a chemical attack on the paint film, degrading it to a sludge-like consistency that is then rinsed from the parts.

The principal advantages of this class of stripper are the relatively low chemical and disposal costs. Disadvantages are that they are effective on a limited number of coatings, are safe only on magnesium and ferrous metal parts, incur high energy costs in operation, and are hazardous to the operator.

These products were formerly a mainstay in the automotive and heavy equipment industries, but that use has declined as more resistant coatings have been introduced. Current users include manufacturers of such home appliances as hot water heaters, gas heaters, and air conditioning

units. Paint hook stripping is also a popular use for these products.

Other aqueous strippers include hot solutions of sulfuric or chromic acid, but their use is generally restricted to coatings impossible to remove by other means within time constraints.

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## Solvent Paint Strippers

Currently the most important paint stripping formulations have a solvent base. These strippers are the most widely used in the industry. This would include both products thickened for spray application and those thinned for immersion. In both sub-types may be found acid or alkaline materials, chlorinated and nonchlorinated products. For this discussion, solvent paint strippers will be divided into chlorinated and nonchlorinated products.

Among chlorinated solvent-based paint strippers, the premier solvent is usually methylene chloride, although in a few immersion-type products, orthodichlorobenzene, trichloroethane, and perchloroethylene also are used. Use of these other chlorinated solvents may allow the stripper to be used hot, at temperatures as high as 140° to 160°F. Methylene chloride-based products, because of their 104°F boiling point, cannot be used above about 90°F without incurring substantial evaporation losses. Together with the chlorinated solvent base, these products generally contain 10 to 30 percent co-solvents, usually alcohols, ketones, esters, and/or aromatic solvents such as toluene; 5 to 15 percent water plus so-called activators such as ammonia, various amines, formic acid, phenol, cresol, etcetera. Finally, they may contain minor amounts of surfactant, thickeners, corrosion inhibitors, and evaporation retardants. If the product is used in an immersion process, it may have 10 to 15 percent water or oil to form a floating layer as a seal to retard evaporation. These products—generally potent mixtures—are successful on the more difficult stripping jobs.

The viscous, spray-on products are used for large parts or assemblies that cannot be immersed, for detail stripping where only certain areas need to be stripped, and for stripping small quantities of parts whose numbers do not justify the installation expense of an immersion stripping line.

These strippers, whether thick or thin, are versatile, effective, and reasonably economical. They are so popular that they might be found in any industrial setting. They would certainly be the product of choice for most applications if there

were not so many health and environmental concerns about their use.

These concerns currently center around methylene chloride itself. Methylene chloride has been among the most widely studied of the commercial organic solvents. There is a broad database covering the health effects on humans exposed to various levels for extended periods of time, up to an entire working lifetime. The significance of this data, combined with animal studies of various species exposed in various ways, is the subject of some debate. Wherever the truth lies, however, the problems associated with its use are well known and technologies exist to control these problems.

Naturally there is a considerable impetus to avoid these problems altogether by using a stripper based on solvents other than methylene chloride or other halogenated hydrocarbons. It should always be kept in mind, however, that alternate solvents or technologies may appear to be advantageous by comparison only because much less is known about the alternative approach. The old adage still applies that "absence of evidence is not evidence of absence."

The other broad category of solvent-based products is nonchlorinated solvents. These include such diverse materials as *N*-methyl pyrrolidone, various glycols or glycol ethers, dimethyl sulfoxide, and others. These solvents are difficult to classify into a coherent group, but they usually seem to be fairly polar, water soluble, and capable of entering into hydrogen bonding. These products generally include a high concentration (30 to 40 percent) of an alkyl or alkanolamine and an oily layer as a seal to retard evaporation. They are, almost without exception, immersion products.

Because they tend to be much slower acting than methylene chloride-based products, these strippers are operated hot, from 140° to 250°F. At these elevated temperatures, they are quite effective and approach or even surpass the performance of methylene chloride-based strippers. They seem to be more selective in their action, however, and do not usually strip as broad a spectrum of paints as a methylene chloride-based product would.

Products of this type are currently used to strip rejected parts in a host of industries including office equipment and furniture, aircraft and automotive wheels, turbine engine manufacture or remanufacture, casket manufacturing, oil drilling rig equipment, wellhead equipment, and air conditioner and air compressor manufacturing. This list would be as varied as that for chlorinated strippers.

These products suffer from several disadvantages. First, the initial cost is usually substantially higher—sometimes three times as high as an effective methylene chloride product. This initial high cost, however, is usually balanced somewhat by longer tank life and lower disposal costs. High operating temperatures cause high operating costs because of high energy costs. Stripping may be somewhat slow and selective.

The chief advantage of these products is the absence of chlorinated solvents. Generally these products are formulated to also eliminate other ingredients that cause disposal problems, such as chrome and phenols or cresols.

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## Mixed or Semi-aqueous Strippers

This last category is the newest of the three classifications. There are not many representative products in this group, but they are attracting considerable interest. Mixed or semi-aqueous strippers contain nonchlorinated solvents and water in roughly equal portions. Based on current information, they seem to be relatively innocuous to both the user and the environment. They strip even the most resistant aircraft and aerospace paints and are available for both immersion and spray-on applications. Since these are relatively new products, they are not in wide use.

Products in this category are currently used to strip rejected parts for manufacturers of heavy equipment, oil rig drilling equipment, aircraft and aerospace equipment, computers, railroad rolling stock equipment, and many other types.

Mixed products offer several significant advantages. First, this category includes the only nonchlorinated *thickened* strippers that are effective on the most resistant paints, such as epoxy primers. Thickening allows use on large parts or assemblies that cannot be immersed in a strip tank. Second, mixed products are relatively easy to dispose of since they generally are free of the chrome, phenol, and other components that create disposal problems. Any waste rinsewater generated during their use is also relatively easy to handle.

Disadvantages of mixed or semi-aqueous strippers include their relatively high cost compared to chlorinated strippers. This high initial cost may be completely or partially balanced by lower overall operating costs, however. A second disadvantage is longer stripping time, although this may be a more apparent than real drawback, as usually only 15 to 45 minutes more time is

required, which is often insignificant in the entire strip and repaint schedule.

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## **Conclusion**

Summing all of this up, it would appear that chlorinated solvent paint strippers and, in particular, those based on methylene chloride, con-

tinue to be the most widely used type of paint stripper, in spite of the increasing problems associated with their use. Gradually, as regulations become more and more restrictive, more and more companies are changing to the nonchlorinated solvent-based or semi-aqueous variety of stripper. It is expected that this change will continue at a gradual pace unless new regulations or restrictions accelerate this process.

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# **ORIGINAL EQUIPMENT MANUFACTURING**

## ***Substitute Solvent & Non-solvent Alternatives***

**Chair: Christine Whittaker**  
*Office of Risk Reduction Technology  
Health Standards Division  
U.S. Occupational Safety and Health Administration*

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# NMP Formulations for Stripping in the OEM Market Sector

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## Introduction

*N*-methyl pyrrolidone (NMP) is a recognized alternative to methylene chloride-based solvent systems as well as other organic-based solvent systems because of its known effectiveness (Palmer, 1978; Nelson, 1988; Hearst, 1987; Francisco, 1988; Werschulz, 1986) and very low volatility. The low volatility drastically reduces the flammability hazard (NMP's flash point is 199°F). The low volatility also reduces evaporative losses that contribute to worker exposure and environmental pollution. A major drawback to NMP usage in this industry is its high cost. Although very effective on most paints, the cost of NMP makes it prohibitive to use as the sole solvent in a stripper formulation.

The purpose of our recent research program on paint stripping compositions has been to examine NMP solvent blends and attempt to define synergistic combinations that will have several key characteristics: effectiveness, low cost, low toxicity, low volatility, high flash point, environmental acceptance, and potential recyclability. No one blend is expected to fulfill all requirements, but synergistic solvent combinations would be applicable by simple adjustments to very specific market niches.

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## Experimental Procedures

Solutions were spot tested on the paint panels for stripping effectiveness. For cured alkyd and epoxy coatings (see Appendix A for formulations), only film lifting from the substrate was considered effective removal. The time between application of the solvent blend to the panel and the time necessary for complete lifting of the film was defined as the "lift-time." The average of three spots was reported. All experiments were done at room temperature.

Solvent blends were also tested on uncured automotive paints: a black enamel, white enamel, and a solvent-borne clear coat over a waterborne base coat. Effectiveness of the solvent blend was measured by applying several drops to the air-dried paint (for 2 days), covering the spot, and, after 10 minutes, gently wiping the film surface. A relative performance scale of 0 to 5 was used with 0 = no effect; 1 = 0 to 30 percent paint removal; 2 = 30 to 50 percent paint removal; 3 = 50 to 70 percent removal; 4 = 70 to 90 percent removal, and 5 = >90 percent removal.

All solvents were obtained from Aldrich Chemical Company or Fisher Scientific with the exception of the following items: *N*-methyl pyrrolidone, Gamma-butyrolactone, ARCOSOLV<sup>®</sup>PM Acetate propylene glycol monomethyl ether acetate, and ARCOSOLV<sup>®</sup>DPM Acetate dipropylene glycol monomethyl ether acetate, which are products of ARCO Chemical Company. Aromatic 150 and Isopar<sup>®</sup>M are products of Exxon Chemical Company. XTOL<sup>®</sup>P tall oil fatty acid is a product of Georgia Pacific Corporation.

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## Results

ARCO has focused its attention on NMP because of general industry knowledge that NMP works very well by itself. In addition, NMP-aromatic solvent blends demonstrate stripping effectiveness roughly equivalent to NMP alone (Palmer, 1978). However, before screening numerous solvent blends, we compared NMP to several other solvents and a methylene chloride-based blend. The results are listed in Table 1.

This test was performed in part to assess the efficacy of this experimental technique for screening relative performance of solvent-based strippers as well as making comparisons of NMP to other solvents. The test was simple, fast, and considered

**Table 1.—Performance of paint stripping solvents.**

SOLVENT SYSTEM	TIME TO PAINT	
	LIFT/BUBBLING (MIN:SEC)	% REMOVED AFTER 60 MIN.
Methylene chloride + toluene + methanol (85/10/5)	1:00	5
N-methyl pyrrolidone	1:45	100
Acetophenone	6:00	100
ARCOSOLV PM	No Lift	80
ARCOSOLV PMAc	No Lift	80
ARCOSOLV DPMAc	No Lift	0
Xylene	No Lift	0
Furfuryl alcohol	No Lift	100
Gamma-butyrolactone	No Lift	90
DBE (dibasic esters) <sup>1</sup>	No Lift	80
Propylene carbonate	No Lift	0

<sup>1</sup>Product of DuPont Corporation

to be very reliable for making simple comparisons of one solvent system to another.

As indicated in Table 1, the methylene chloride-containing solvent blend stripped the alkyd coating the fastest; however, after 60 minutes, the lifted film dried out and re-adhered to the aluminum substrate. Clearly, speed is an advantage but the evaporation rate can be a problem because of readhesion. NMP is the second fastest at lifting the film and no readhesion occurs because of the slow evaporating characteristic of NMP. Acetophenone is somewhat slower but still effective at lifting the film. The remaining solvents, some of which are claimed to be effective paint strippers in combination with other active solvents, fail to cause lifting. Although some of these solvents soften the film and enable removal with scraping, mechanical work is necessary to get the film off the surface.

While pure NMP is a very effective solvent for stripping, it is not an economically favorable option. Blending NMP with other organic solvents can lower cost but, typically, performance is lost (as indicated in Table 2). Propylene glycol monomethyl ether acetate-NMP blends are not as effective as NMP, and performance decreases when glycol ether acetate content is increased.

**Table 2.—Effect of diluent on stripping performance of NMP-based solvent systems.**

WT%NMP/WT%PMACETATE <sup>1</sup>	ALKYD	2-PART EPOXY
100/0	2.0	3.5
80/20	2.5	7.5
60/40	4.0	9.5
40/60	5.0	20
20/80	11.5	93
0/100	No Lift	No Lift

<sup>1</sup>ARCOSOLV PMAcetate (propylene glycol monomethyl ether acetate)

Stripping effectiveness of an NMP solvent blend is expected to be dependent upon the type of cosolvent. A broad series of cosolvents have been screened to determine relative effectiveness of different cosolvent classes as diluents for NMP-based

stripper compositions. The results, which have been discussed elsewhere (Sullivan, unpubl.), indicate two general controlling trends, as summarized in Figure 1. First, NMP performance is inhibited by polar solvents, whereas nonpolar solvents provide synergistic benefits. Secondly, for a group of diluents with approximately the same polarity, the performance increases with increasing volatility. However, the implication of this second trend is that flammability concerns conflict with performance.

### ■ Cosolvent polarity

- Performance increases as cosolvent polarity decreases.
- Glycol ethers and glycol ether acetates show good performance in combination with NMP.
- Aromatic solvents show synergy.

### ■ Cosolvent volatility

- Performance increases as cosolvent volatility increases.

**Figure 1.—General trends on diluent effects of NMP solvent blends.**

## Ternary Blends

Perhaps the most interesting aspect of this screening study is the crude relationship between cosolvent polarity and effectiveness. Very nonpolar, low-cost solvents such as mineral spirits are not miscible with NMP, but the trend suggests that NMP blends with mineral spirits might perform very well. To test this hypothesis, two different ternary solvent blends were formulated and compared to binary blends. The results are provided in Table 3.

The ternary blends of Table 4 show increased performance relative to the binary blends. However, the NMP content is significantly lower in both of the ternary solvent blends; therefore, the cost of the formulated products will be lower.

A possible explanation for this unusual behavior may be the subtle differences in surface wetting and phase partitioning at the coating-solvent blend interface. NMP is not miscible with mineral spirits; therefore, NMP may have a strong thermodynamic driving force to phase separate from the mineral spirits blend and diffuse into the moderately polar paint film (Fig. 2). Surface wet-

**Table 3.—Relative performance of ternary NMP blends.**

SOLVENT BLEND	LIFT TIME (MINUTES)	
	ALKYD	2-PART EPOXY
A. 40% NMP 60% ARCOSOLV PMAcetate	5	20
B. 33% NMP 33% Mineral spirits 33% ARCOSOLV PMAcetate	3	10
C. 40% NMP 60% Aromatic 150 <sup>1</sup>	3.5	8
D. 31% NMP 47% Mineral spirits 22% Aromatic 150 <sup>1</sup>	2.5	6

<sup>1</sup>Aromatic 150 is a product of Exxon Chemical Company

**Table 4.—Non-methylene chloride strippers.**

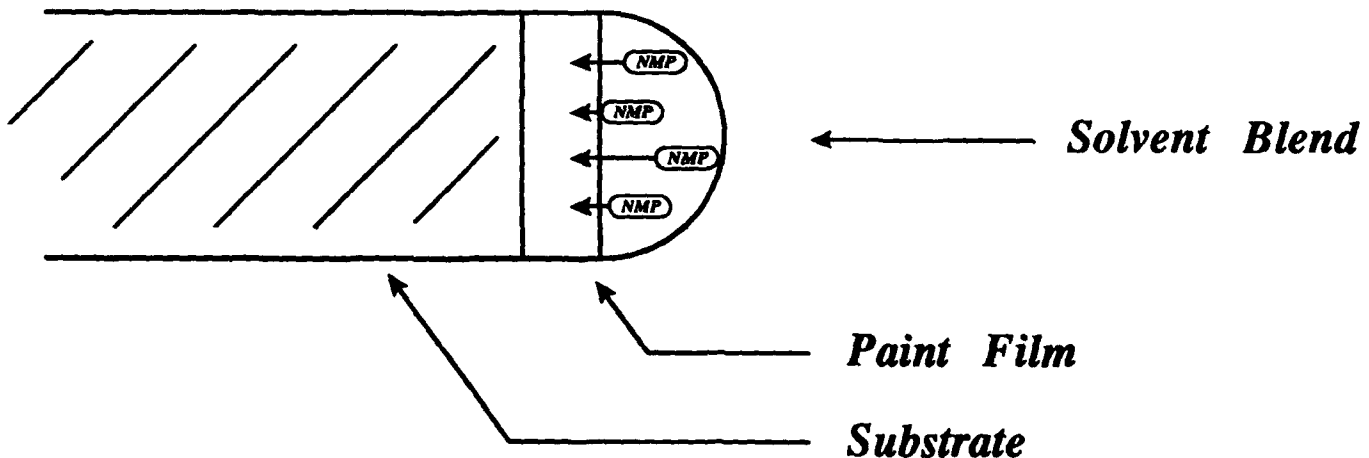
SOLVENT COMPONENT	SOLVENT BLENDS				
	A	B	C	D <sup>1</sup>	E
NMP	30	30	30	30	100
Mineral spirits	35	35	—	—	—
Isopar M	—	—	35	—	—
Xylene	35	—	—	—	—
Aromatic 150	—	35	35	70	—
Flash Point (°F) (Seta)	99	134	158	151	186
Relative Performance <sup>2</sup>					
Black enamel	5	5	5	5	5
White enamel	4.3	4.3	4.6	4.6	5
WBBC/SBCC	2	2	1.6	3.6	4.6

<sup>1</sup>U.S. patent 4,120,810

<sup>2</sup>Covered spot (10-minute soak), 0–5 relative scale, see text

ting will clearly play a significant role in such phase partitioning, and surfactants can obviously influence this partitioning.

Because NMP is immiscible with aliphatic hydrocarbons, a third solvent is necessary to get both the synergistic and cost-reducing benefits of the aliphatic hydrocarbon. Interestingly, the possible range of such combinations is limitless because of the large variety of solvents that can be chosen as the miscibilizing agent. Also, a large variety of low-cost aliphatic solvents are available to the formulator.



**Figure 2.—Schematic of solvent blend, paint film, substrate interface.**

Examples of other formulation options are listed in Tables 4 and 5. The relative performance data for these blends on the three air-dried automotive paints are provided.

**Table 5.—Non-methylene chloride strippers—no aromatic content.**

SOLVENT COMPONENT	SOLVENT BLENDS					
	A	B	C	D	E	F
NMP	40	30	33	30	38	37
ARCOSOLV PMAcetate	60	40	—	—	—	—
ARCOSOLV DPMAcetate	—	—	33	44	—	—
Mineral spirits	—	30	33	—	38	—
Isopar M	—	—	—	26	—	37
XTOL P	—	—	—	—	24	26
Flash Point (°F, SETA)	126	114	134	171	131	170
Relative Performance <sup>1</sup>						
Black enamel	5	5	5	5	4.6	3.0
White enamel	5	4	3.6	2.3	4.3	2.6
WBBC/SBCC	3.3	2.0	1.6	1.3	1.0	1.0

<sup>1</sup>Covered spot (10-minute soak), 0–5 relative scale, see text

The examples of Table 4 depict NMP-aliphatic-aromatic blends with varying composition and flash points. Versatility is a key advantage of these ternary blends. Not only are the blends cost effective, but the flash point is readily adjusted by the appropriate choice of cosolvents. Higher flash cosolvents, such as isopar M and aromatic 150, yield higher flash blends.

In Table 5, a range of solvent blends is provided that do not contain aromatic solvents for those markets where the user prefers to avoid aromatic solvents. The blends lift the paint films effectively and, as in Table 4, the flash points vary depending upon the flash points of the cosolvents that are chosen. Versatility is again a clear advantage of these ternary blend systems. The glycol ether acetates make good compatibilizers as does the XTOL<sup>®</sup>P—a product derived from tall oil fatty acids.

For all of the blends of Tables 4 and 5, relative performance has been based upon the ability to

easily wipe the air-dried film from an aluminum substrate after only 10 minutes soak time. For more difficult films and thicker layers of films, such as the solvent-borne clear coat over the waterborne base coat, longer contact times will ensure complete removal of the partially dried paints.

Clearly, the blends described here should provide a great deal of versatility to the formulator in the industry. Thickeners are often required, and ethyl hydroxyethyl cellulose (available from Aqualon®) is very effective for some of the ternary blends. Activators, such as formic acid, are claimed to add stripping power to methylene chloride-based formulations. However, such activators should be examined for utility in these novel blends.

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## Conclusion

NMP is a proven performer for paint stripping applications. The work reported here summarizes new concepts in blending NMP with other organic solvents to provide effectiveness and economic

viability. The NMP ternary solvent blends have unique attributes, primarily because of the broad formulation options available to the end user. Low volatility, cost-effective formulations that yield high flash-point products are obtainable.

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## APPENDIX A

### Formulations for Cured Alkyd and Epoxy Coatings

**White Alkyd Air Drying Enamel**

<b>CARGILL ALKYD 51-5150</b>	<b>98.0</b>
<b>Mineral Spirits</b>	<b>17.0</b>
<b>Lecithin</b>	<b>3.0</b>
<b>Thixatrol GST</b>	<b>2.0</b>
<b>TIPure R-900</b>	<b>246.0</b>

***Disperse***

<b>CARGILL ALKYD 51-5150</b>	<b>503.0</b>
<b>Mineral Spirits</b>	<b>52.0</b>
<b>6% Cobalt Drier</b>	<b>2.0</b>
<b>6% Ziro Catalyst</b>	<b>4.0</b>
<b>5% Calcium Drier</b>	<b>3.0</b>
<b>Anti-Skinning Agent</b>	<b>1.0</b>

**White Epoxy Polyamide Enamel**

**Part A**

<b>Araldite 471-X-75</b>	<b>205</b>
<b>SR-82 Silicone Resin</b>	<b>4</b>
<b>TIPure R960</b>	<b>267</b>

***Disperse***

<b>Araldite 471-X-75</b>	<b>200</b>
<b>Arcosolv PM</b>	<b>112</b>
<b>MIBK</b>	<b>112</b>

<b>Subtotal</b>	<b>900 Lbs</b>
<b>Yield</b>	<b>84.89 Gal</b>

**Part B**

<b>Hardener HY-815</b>	<b>100</b>
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<b>Subtotal</b>	<b>100 Lbs</b>
<b>Yield</b>	<b>12.35 Gal</b>

<b>TOTAL</b>	<b>931.0 Lbs</b>
<b>YIELD</b>	<b>100.0 Gal</b>

<b>TOTAL A + B</b>	<b>1000 Lbs</b>
<b>YIELD A + B</b>	<b>97.2 Gal</b>

# Aromatic Solvent Strippers for Automotive Paint Booth Maintenance

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## Introduction

Several automotive assembly plants are now using paint strippers based on aromatic solvents for paint booth cleaning. These products offer a cost-effective replacement for methylene chloride paint strippers, while maintaining an acceptable level of performance. The use of these products does not require the extensive equipment or procedural changes necessary for other methylene chloride alternatives.

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## Alternative Paint Strippers

The aromatic solvent strippers described here are used exclusively on uncured paint and are most frequently used to clean oversprayed paint from paint booth walls, windows, and equipment. These thixotropic materials are applied by low-pressure spray or flow onto the coated surfaces and allowed to contact the surface for 5 to 10 minutes. After sufficient time has passed, the surface is rinsed with high-pressure water to remove the stripper and paint residue.

A typical formulation of an aromatic solvent-based stripper contains 50 to 80 percent aromatic solvent, 5 to 30 percent of a cosolvent, and varying amounts of emulsifier, thickener, and odor mask, if desired. The aromatic solvent used as a base is a petroleum naphtha with a flash point between 105 to 155°F. These solvents are somewhat active alone, but performance is greatly enhanced by the use of an active cosolvent. The choice and amount of cosolvent have the most pronounced effect on performance.

Applicable solvents include *N*-methyl pyrrolidone, furfuryl alcohol, the whole range of glycol ethers, and esters. In many cases it is helpful to

utilize a combination of solvents to widen the application range of the stripper.

The use of emulsifier in these formulations is intended to improve rinsing with water. Anionic surfactants are generally preferred, as they are less likely to interfere with paint detackification or cause problems with existing waste treatment processes. However, small amounts of nonionic surfactants are also used to reduce streaking of the surfaces after rinsing.

The use of a thickener is most important with materials used on paint booth walls. The proper viscosity and flow characteristics are critical in minimizing the amount of stripper necessary to clean a given area. The material must be easily pumpable, yet cling to vertical surfaces long enough for the stripper to be effective. If the proper viscosity is not achieved, multiple applications may be required, increasing volatile organic emissions and costs. A variety of thickeners can be used, including cellulose in systems with high cosolvent content.

The primary hazards associated with these strippers are due to the flash point and the potential exposure to solvent vapors. Since these solvents can contain varying amounts of xylene, toluene, ethyl benzene, and naphthalene, exposure to vapors should be minimized with protective breathing devices. While these materials continue to contain hazardous ingredients, they do offer a significant advantage over methylene chloride.

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## Performance

In almost all cases, methylene chloride strippers remove paint more quickly than these products in laboratory tests, but the difference in performance is insignificant considering plant practices. Since

it requires a substantial amount of time to coat a paint booth, strippers generally remain in contact with the painted areas for at least 5 minutes. This allows for the use of a somewhat slower stripper than methylene chloride. (See Figures 1, 2 and 3 for a comparison of time required to remove different types of paints.)

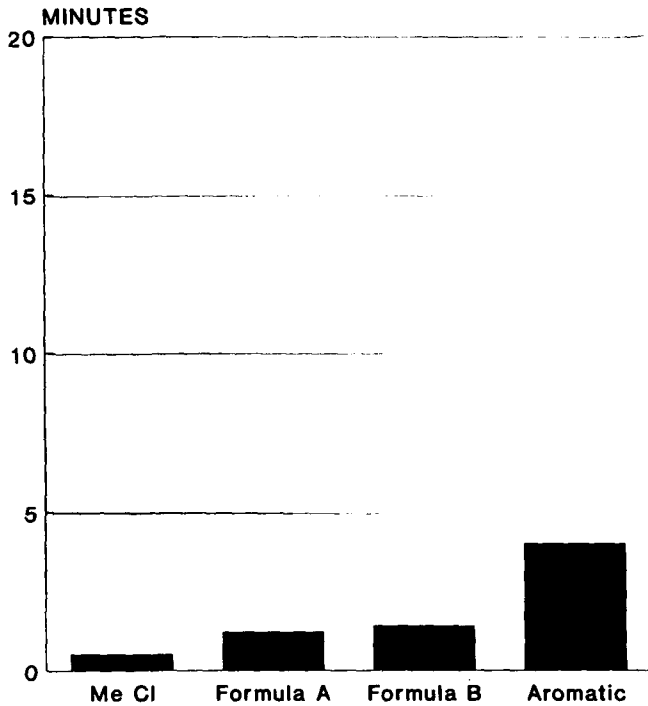


Figure 1.—High-solids enamel.

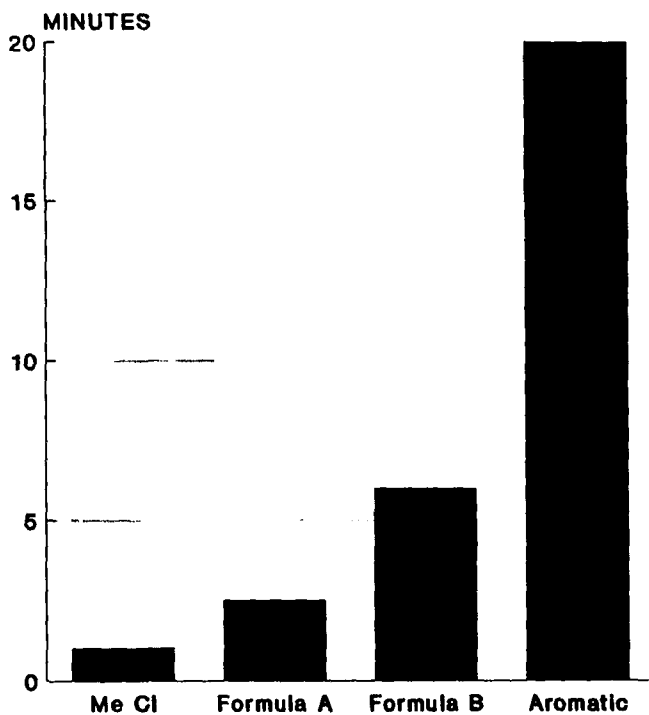


Figure 2.—Polyurethane clear coat.

The effectiveness of aromatic solvent strippers on typical automotive finishes depends largely on

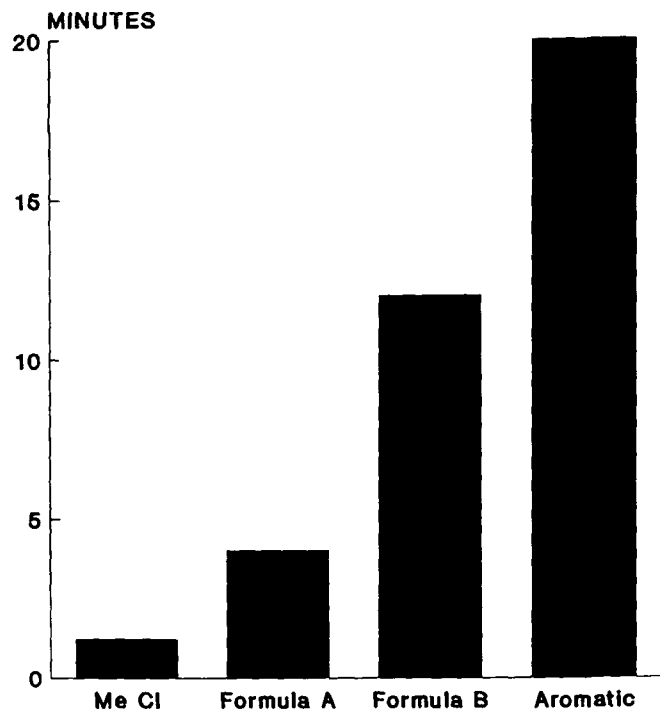


Figure 3.—Two-part clear coat.

the type and content of the cosolvent. High-solids enamels can be effectively removed with materials containing relatively low (10 percent) concentrations of cosolvent, while polyurethane clear coats require a significantly higher concentration (25 percent) of cosolvent. The new two-part clear coats are especially difficult to remove and may require multiple applications or the use of even higher cosolvent concentrations. (See Table 1 for typical formulations.)

Table 1.—Typical formulations.

	FORMULA A	FORMULA B
Aromatic solvent	68.25	76.75
Cosolvent	25.00	10.00
Thickener	0.75	1.25
Emulsifier	6.00	12.00

## Waste Management

In a typical assembly plant operation, both stripper and paint residue are washed into the detackification system. When properly managed, this additional wastewater, paint, and stripper should not cause any problems with the normal functioning of the system.

Since the majority of the stripper is volatile, paint is the most significant component entering the treatment system. In plants where an aqueous detackification system is not in use, the wash-

water from stripping can be collected and treated separately with acid/polymer or alum/polymer combinations to remove emulsified solvent and paint solids.

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## Cost

The material cost of aromatic solvent strippers is generally 10 to 50 percent higher than their methylene chloride counterparts on a pound-for-pound basis. However, training of maintenance crews in the proper application of thin stripper films and the formulation of products to provide good clinging properties can minimize the use of these products. In many cases, the overall cost of stripping is comparable to using methylene

chloride. One of the major advantages to this system as opposed to other alternatives is simplicity. These materials are used in very much the same manner as the previously used strippers and require very little investment in equipment, space, and manpower.

Other practices and products are constantly being developed to decrease the amount of stripper used to reduce costs, volatile organics, and worker exposure. One of these practices is the use of a water soluble coating that is applied to the booth after cleaning. This coating makes the paint easier to remove, allowing for less frequent stripping. Continued work in this direction should eventually lead to strippers that do not use hazardous or volatile solvents to clean paint booths.

# Alternative Methods for Uncured Paint Removal In Automotive Manufacturing

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## Introduction

Historically, methylene chloride served as the primary chemical agent for paint spray booth cleaning in automotive assembly plants. Methylene chloride was the active ingredient in thickened solvent paint-stripper formulations that were applied to oversprayed paint deposits on spray booth surfaces at the end of the production shift. After allowing adequate time for reaction, softened paint deposits and paint stripper were washed with water into the spray booth water system.

Methylene chloride exhibited a number of unique qualities that made it especially useful for paint spray booth cleaning. These were (1) a high degree of efficacy in softening and/or dissolving paint deposits, including cured paints; (2) safety with regard to fire risk, due to methylene chloride's high flash point; and (3) low contribution to volatile organic compound (VOC) emissions, as a result of methylene chloride's classification as non-photochemically reactive.

Unfortunately, methylene chloride also possessed a number of less desirable characteristics that eventually resulted in its virtual elimination from use in automotive assembly spray booth cleaning. These include (1) suspected deleterious health effects for chronically exposed workers; (2) classification as a priority pollutant with regard to wastewater discharge requirements for total toxic organics (TTO) under the Clean Water Act; and (3) operational drawbacks caused by its rapid evaporation rate and its tendency to leave insoluble pigment film on spray booth surfaces following water rinsing.

By the mid-1980s, automotive manufacturers had largely replaced methylene chloride-based products with alternative solvent blends, primarily over concern for the health of chronically exposed workers.

Concurrently, a major change in paint formulation technology aided automotive manufacturers in shifting from methylene chloride to alternative, nonhalogenated solvents. Low-solids lacquer paints were largely replaced by high-solids enamels and base-coat/clear-coat technology to meet more stringent volatile organic compound emission standards. Methylene chloride had been particularly useful to the booth cleaning operation because of its unique ability to remove air-cured lacquer paint. While higher-solids paints pose their own cleaning challenges, they require heat to cure. A variety of nonhalogenated solvents were soon identified that exhibited varying degrees of effectiveness in dissolving the uncured deposits of paint using the new paint technologies.

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## Replacement Formulations for Methylene Chloride

Numerous formulations have been developed for nonhalogenated solvent-based paint strippers. Typically, these consist of a hydrocarbon solvent and a more polar cosolvent. Thickening agents, surfactants, and other additives are often incorporated into the formulas.

In general, alternative solvent formulations compare to methylene chloride as follows:

- **Stripping activity:** New formulations provide comparable effectiveness. Losses in

time were compensated by changes in work schedules and methods.

- **Fire safety:** A number of nonhalogenated solvents with high flash points (greater than 100°F or 140°F) have been employed. While fire risk versus methylene chloride is somewhat greater, the routine high safety standards of the spray booth have minimized this drawback.
- **Volatile organic compound emissions:** Unlike methylene chloride formulations, essentially all of the solvent portion of the new formulations contributes to VOC emissions.
- **Health effects:** While chronic exposure to any organic solvent is considered potentially harmful, the replacement of methylene chloride is generally believed to be a positive step.
- **Total toxic organics contribution:** Replacement of methylene chloride generally improved plants' ability to meet waste water discharge requirements.
- **Application considerations:** Replacement formulations generally contain slower-evaporating solvents. However, insoluble pigment film remaining after water rinsing continues to be a problem.

While the conversion from methylene chloride to other technologies for booth cleaning has been largely completed in the automotive assembly industry, a number of concerns remain. The advent of the Clean Air Act amendments makes the reduction of volatile organic compound emissions from the booth cleaning operations an increasingly important issue. Balancing the reduction of VOC emissions within the constraints of cost performance goals, limited time schedules, and respect for worker safety will be the challenge of the 1990s.

In developing a booth maintenance program to reduce VOC emissions, a number of different options were investigated. A major constraint was that the program had to provide comparable performance in the same time frame as existing programs.

New paint stripping tests were developed to quantify paint stripper usage. These tests were then conducted on different degrees of paint overspray to generate conditions that would better correlate with an automotive plant. The overspray standards selected were light overspray (which would be typical of paint overspray on most booth

walls and windows), moderate overspray (representative of the robot cabinets and surfaces directly behind painting stations), and thick and heavy oversprays (found on grates and the center track of the booth).

Initial paint stripping tests were conducted to quantify the effectiveness of different types of strippers currently being used in the industry. One parameter specifically explored was the impact of paint stripper viscosity on usage rate. Since many plants are using line purge solvent blends or non-viscous paint strippers to clean the booths, a comparison was made between a viscous stripper and a nonviscous stripper.

A Nalco paint stripper was selected as the viscous stripper. This product is a thixotropic material having a viscosity of approximately 20 cps at high shear (spraying conditions) and approximately 600 cps at low shear (vertical sagging conditions). These ranges are compatible with ease of pumping and optimum paint stripping activity on vertical surfaces.

For the nonviscous stripper, a simple blend using the same solvents as those in the viscous product was selected. With the same solvent package in both products, the effect of viscosity could be studied.

Results of these tests showed that substantially more of the nonviscous stripper was required to remove the paint overspray than was the case using the viscous stripper. The usage rate was typically 10 to 20 times higher with the nonviscous stripper on each degree of overspray. Thus, those plants using a nonviscous stripper could achieve a major reduction in VOC emissions usage by switching to a viscous paint stripper.

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## Nalco VOC Minimization Program

Further research indicated that the application of a water-rinsable booth masking with a viscous paint stripper would also provide a substantial reduction in VOC emissions. With the masking providing a protective barrier coating between the paint and the booth substrate, no paint stripper was required on light overspray areas. The overspray and masking could be easily rinsed off with just water. On moderate overspray, stripper usage was reduced by more than 50 percent.

With this degree of overspray, a small volume of stripper was necessary to perforate the paint film to allow the water to reach and dissolve the water-soluble protective masking underneath. As

would be expected, a lesser reduction in stripper usage was observed on heavy and thick oversprays.

A VOC Minimization Program was then developed, based on this information, to help automotive plants meet their restrictive VOC emission limits. By eliminating the use of stripper on light overspray areas and reducing the amount used on moderate overspray areas by more than half, an automotive plant could significantly reduce its VOC contribution from its booth maintenance.

Another major benefit with the VOC Minimization Program is improved booth cleanliness. Typically, with any type of paint stripper, a noticeable residue accumulates on the booth surfaces after one or two weeks. This residue is from the inorganic pigments in the paint, which cannot be dissolved by the paint stripper and which are precipitated out onto the booth surface. This phenomena can be shown through examination of a steel substrate after repeated applications of paint and paint stripper with a scanning electron microscope (SEM).

When a masking is employed, the booth substrate remains clean, with no build-up of pigment. Various maskings can be used to protect all surfaces, including windows and hoses. After 10 ap-

plications of paint and paint stripper, the steel remained as clean as at the beginning of the test. No inorganic residue was detected by the SEM analyses.

The maintenance process involves applying the masking to a clean booth before production and allowing 15 to 60 minutes for it to dry. After the production shift ends, the maintenance department applies a controlled amount of paint stripper to the heavier overspray areas. After a 15 to 30 minute contact time, the stripper, dissolved paint, and masking are rinsed off with water. The final step is the reapplication of the masking.

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## Summary

The potential benefits of this VOC minimization program include (1) VOC emission reduction, (2) improved booth cleanliness/reduced dirt-in-paint potential, (3) reduced contribution to waste water discharge TTO limits, (4) reduced solvent exposure for workers, and (5) total program cost reduction.

In comparison to obsolete methylene chloride products or alternative solvent formulations alone, this new approach offers significant advances in overall performance and worker safety. Further research should continue to provide improvements in both categories.

# Cryogenic Paint Stripping

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**C**ryogenic paint stripping is a new, patented method of removing built-up paints or coatings from hooks and fixtures normally found on the paint production line. The hook (or fixture) is put in a cabinet where it is frozen and embrittled with liquid nitrogen. It is then impacted with high-speed nonabrasive plastic pellets that fracture the coating and debond it from the substrate. The process, which takes advantage of extreme cold instead of heat or chemicals to remove coatings, is quick, simple, and produces no hazardous waste.

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## Traditional Paint Stripping Methods

Traditional methods of paint stripping such as solvents, hot caustic, pyrolysis, direct burnoff, incineration, and molten salt use heat or chemicals. These processes have one or more disadvantages. Methods that use heat can

- Weaken, anneal, and eventually destroy steel components,
- Weaken welds,
- Detrimentally affect magnets, and
- Cause fires, explosions, and air pollution.

High temperature also precludes use of aluminum and other low melting point materials.

Likewise, methods that use chemicals can produce

- Severe hazardous waste disposal problems,
- Reactions that cause explosions, and
- Hazardous fumes.

These methods are also incompatible with some metals. Lastly, workers must wear cumbersome personal protection equipment.

---

## Cryogenic Paint Stripping

Cryogenic paint stripping uses liquid nitrogen as the refrigerant to produce the low temperatures required for the process. Nitrogen is inert, colorless, odorless, and noncorrosive; it will not burn or support combustion.

Air is a mixture of 78 percent nitrogen and 21 percent oxygen. Liquid nitrogen is obtained by compressing and cooling air until it condenses to a liquid that is then distilled into its components. Liquid nitrogen has a boiling temperature of  $-320^{\circ}\text{F}$  at atmospheric pressure. During the cryogenic paint stripping process, liquid nitrogen vaporizes to nitrogen gas that is returned to the atmosphere.

The coated fixtures are cooled with liquid nitrogen in a specially designed cryogenic cabinet. As cooling progresses, the coating becomes brittle and contracts (shrinks) around the fixture. Because the coating shrinkage is greater than that of the fixture, tensile stresses develop, producing a brittle, highly stressed surface.

While in this state, the fixture is struck by high velocity, nonabrasive polycarbonate pellets that crack the coating and debond it from the substrate. The result is clean fixtures that do not need additional washing.

## The Equipment

All parts to be stripped are placed onto a loading tree and then mechanically lifted onto a spindle at the top of the cabinet. This spindle rotates the

loading tree in front of the throwing wheels throughout the cycle.

Hooks are cooled by liquid nitrogen until the coating becomes embrittled and then are struck by high velocity media from the throwing wheels. The mixture of media and paint chips is collected at the cabinet bottom and conveyed to a two-deck separator that classifies it into oversized and undersized chips and media (the pellets). The paint chips are collected as compact solid waste and can be disposed of economically. The media is reclaimed and conveyed back to the throwing wheels, and the nitrogen exhaust gas is cleaned of paint dust before being ducted to the outside atmosphere.

The cabinet and components have been carefully designed and constructed for low temperatures. A panel contains controls to operate and optimize the process. Interlocks have been integrated to ensure operator safety.

The equipment is illustrated in Figure 1.

### Performance Capabilities

Alkyd, acrylic, polyester, vinyl, and lacquer coating have been successfully removed from various parts. Because epoxy and urethane coatings are harder to remove, satisfactory results are not always obtained. Coating thickness should be between .010 of an inch and .500 of an inch for best

results; coatings of less than .010 of an inch are more difficult to remove.

Loads are limited to 400 pounds of parts per cycle. Cycle times vary between 5 and 15 minutes, with an average cycle of 10 minutes. Best results are obtained when the parts are loaded so as to expose them to the media blast. However, because the media inside the cabinet rebounds several times, even recesses and shaded surfaces are cleaned well. Round hooks are stripped effectively even though they are touching adjacent hooks on both sides.

### Process Safety

Basically safe, cryogenic paint stripping does not

- Fume, smoke, or pollute.
- Produce hazardous wastes and subsequent disposal problems, and
- Explode or cause fires.

Two safety issues connected with cryogenic paint stripping are

- Preventing oxygen deficiency by ducting the exhaust gas outside the building, and
- Protecting workers against the extremely cold process temperatures by requiring

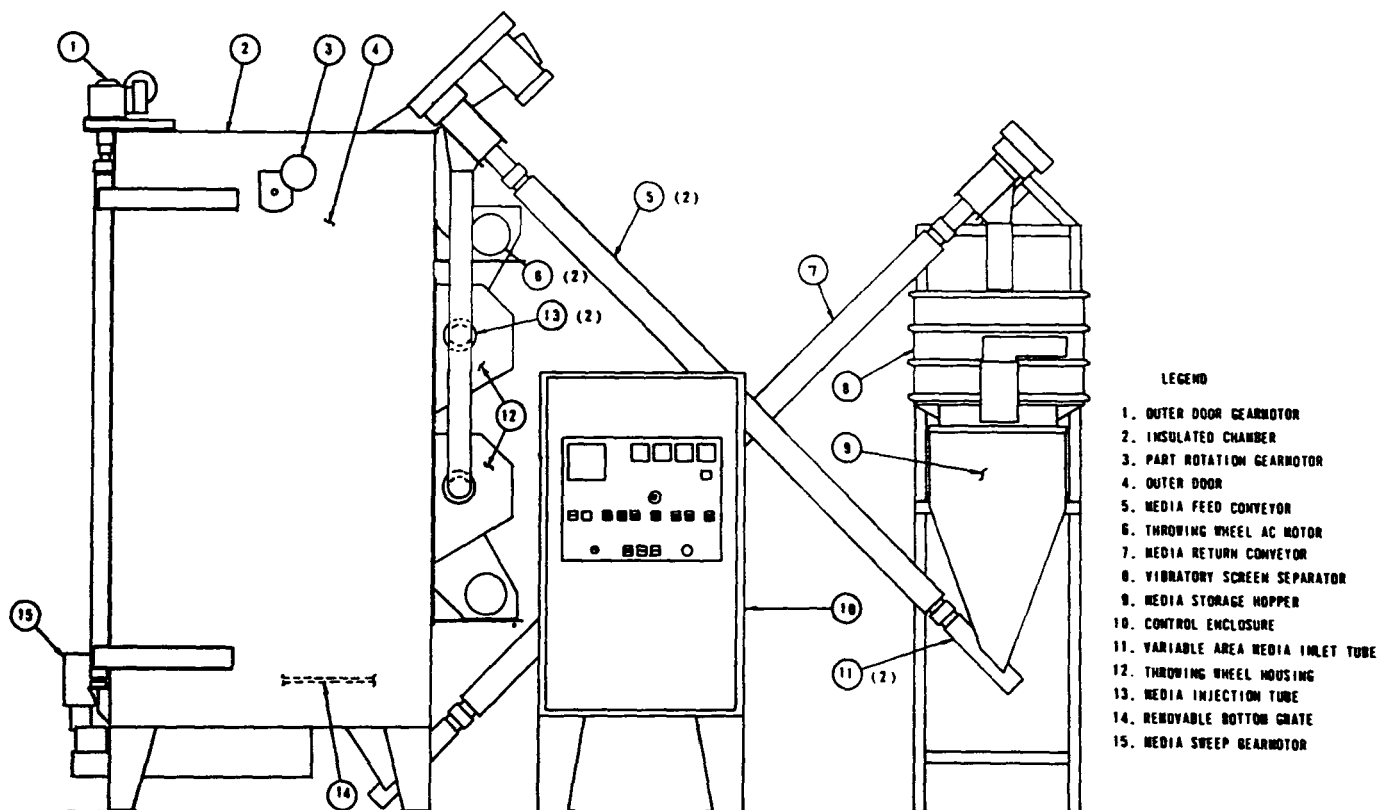


Figure 1.—The CRYO-STRIP® cryogenic coating removal system.

the wearing of gloves during unloading. Cold parts warm quickly and can usually be handled with bare hands within five minutes.

### ***Economics of the Process***

The economics of cryogenic paint stripping depends on the individual customer's operation and requirements. This process is particularly economic when

- Production requirements are high,
- High costs are incurred from disposal of hazardous wastes, and
- Heat and chemicals will damage the hooks or fixtures.

Additional savings can be realized from these other aspects of the process:

- Fixtures do not need to be cleaned or washed after cryogenic stripping.
- Fixtures are usually not damaged by the stripping process.
- Fire or explosion hazards are eliminated from the process.
- Worker safety insurance costs are minimal.

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### **Conclusion**

Cryogenic paint stripping offers a viable alternative to more traditional methods. Although performance guidelines are supplied, only testing can determine the process's success for a given coating on a particular part. Air Products and Chemicals maintains a laboratory and a production scale CRYO-STRIP® machine to test customer parts for evaluation.

# Use of Plastic Media Stripping in Original Equipment Manufacturers' Applications

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**W**hile there has been much publicity about the use of granulated plastic media for aircraft maintenance stripping, not much has been published about the use of this process in original equipment manufacturers' (OEM) applications. Yet, there has been substantial growth in industrial applications since 1978, the year that granulated plastic media was introduced. This presentation will describe and assess the use of plastic media stripping for refinishing new or warranted OEM parts and products.

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## Plastic Media Blasting

Equipment parts or finished products may be rejected by quality control standards because of errors in painting. Such flaws may be only cosmetic, while others present potential failure in corrosion protection systems or in meeting color specifications. It is common practice to attempt spot repairs or to ship large quantities of such rejects to obscure chemical strip shops. Fixtures used to transport parts on paint lines are also sent out to chemical stripping or bake-off facilities to remove thick paint buildup.

Plastic media blasting offers the generators of paint rejects or coated fixtures an acceptable alternative to methylene chloride and other toxic strippers. Many production paint operators or their contract strippers have begun using plastic abrasives in relatively inexpensive direct pressure blast systems to complement their existing processes. Also, a growing number of dedicated "dry stripping" facilities have begun operating around the United States and Canada to provide plastic media stripping services to industry and automobile refurbishers. Many such operations

are trained and certified to perform plastic media stripping.

A wide variety of OEM components and products are being stripped with plastic media today. These range from brass water faucets to zinc die cast automobile mirror housings, to thin gauge steel cabinets for room heaters, to glass headlight lenses on automobiles. Generally, any component or product with significant manufacturing costs can be economically stripped by plastic media blasting.

Plastic media can effectively strip tough coating systems applied by E-coat or powder coat methods, as well as very tough chemical agent resistant coatings (CARC) from military vehicles. There are very few coating systems so tough that plastic media cannot effectively remove them.

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## Advantages of Plastic Media Blasting

There are many advantages to using plastic abrasives in industrial stripping activities. These include:

- The plastic media is highly reusable and easily reclaimed.
- There is reduced danger to workers and environment.
- This is a dry process with reduced waste volume and disposal costs.
- The plastic is neutral in pH level, inert, and noncorrosive.
- The media will not embed in most substrates.

- Anodized, galvanized, phosphated, or clad coatings can be retained undamaged.
- Composite stripping is faster and safer than any alternative method.
- There is no metal embrittlement danger.
- There is no pitting to many metals, including die cast zinc, cast magnesium, aluminum, or brass.
- The process is faster than chemicals in many applications.
- There are no capillary entrapment concerns.
- Plastic stripping often eliminates the need for disassembly of component parts.
- There are lower equipment maintenance costs than for hard grit blasting.
- The process preserves tolerances on delicate parts.
- There is no flash rusting on stripped parts, reducing the urgency to recoat.

## The Plastic Media Blasting Process

While there are many types of plastic resins, only a few are effective as paint strippers. There are currently seven different granulated plastic media types available in the marketplace, although blends of these unique plastic types are also sold and used in limited applications. These can be propelled in airblast systems, similar to sandblasters, or in airless systems using centrifugal wheels to propel media. Most stripping with plastic media is performed manually, either in hand cabinets or in open blasting. Typical blast pressures range from 20 psi to 60 psi. In airless systems, wheel speed may be as high as 14,000 rpm.

All of the plastic media types are reusable, although durability, as well as stripping capability, varies from one type to another. Strip rates are greatly affected by variables like paint resiliency, paint bond, blast pressure, angle of impingement, size of the plastic granules, and distance from the work piece. Therefore, strip rates can be most reasonably described in a range, as shown in Table 1. The times shown are for 1/4" ID blast nozzle (which is the smallest typically used) and a direct pressure air blast system. Siphon-feed systems are not recommended for high-production strip-

ping with plastic media. The media types listed are those recognized in U.S. Military specification Mil-P-85891A.

Table 1.—Plastic media strip rates (1/4" ID nozzle, direct pressure blast).

MEDIA TYPE	RANGE (SQ. FT./MIN.)	TYPICAL RATE (SQ. FT./MIN.)
I	.05- .28	.15
II	.3 -1.5	1.00
III	.6 -1.8	1.25
IV	.5 -1.3	.9
V	.15- .75	.5
VI	.25-1.0	.75

Of course, consumption of the plastic media is another major consideration. The plastic abrasives are reusable through several blast cycles. While figures are available for consumption per blast cycle for each of the types of plastic abrasive, these are not very meaningful, because the time it takes to strip a coating will dictate consumption per operating hour, per part, or per square area. Table 2 indicates the average consumption per nozzle blast hour, assuming a 1/4" ID nozzle in a direct pressure blast system. Usage at two pressure levels are also shown.

Table 2.—Plastic media consumption per nozzle hour.

MEDIA TYPE	AT 25 PSI (IN LBS.)	AT 50 PSI (IN LBS.)
I	12	20 (most blasting at 50 psi)
II	14	24 (most blasting 25-40 psi)
III	18	32 (most blasting 25-40 psi)
IV	20	30 (most blasting 25-40 psi)
V	4	8 (most blasting 40-60 psi)
VI	14	30 (most blasting 20-30 psi)

## Costs of Plastic Media Stripping

While consumption analyzed by operating hour can be useful in predicting costs, the paint coating itself dictates the efficiency of the process. Therefore, Table 3 identifies ranges of consumption per square foot of stripped area for each of the popular media types. These data are based on typical strip rates as shown in Table 1.

Table 3.—Media consumption range per square foot.

MEDIA TYPE	PLASTIC MEDIA CONSUMPTION (IN LBS.)
I	1.2 -6.6
II	.25- .6
III	.35- .66
IV	.35- .6
V	.2 - .3
VI	.4 - .9

Based on Table 3, it appears that it would not be efficient to ever use Type I, or that only Type V should be used given its excellent durability. However, the individual physical characteristics of the media types—especially hardness and specific gravity—are essential for such special finish requirements as maximum surface profile on soft materials, no degradation of soft materials like composites, and minimizing peening effects on thin sheet metal like aircraft skins. The faster stripping plastic types may be too aggressive to meet certain finishing goals. On the other hand, for more durable parts made of anodized cast aluminum or phosphated sheet steel, the more aggressive Types II or III provide much greater strip rates without degrading the substrate or corrosion protective coating, thus reducing overall process costs.

Blast and reclaim equipment should be carefully selected to ensure efficient operation and maximization of the potential savings of plastic media stripping. The blast equipment should be capable of propelling the plastic media without sputtering or erratic flow. An adjustable media flow valve should be included. The recycling media must be cleaned by removing dust (which can severely reduce the strip rate by acting as a buffer) and removing large contaminants like paint flakes or metal shrapnel. Magnetic traps are also strongly advised. Ventilation in standard blast cabinets is

adequate for removing airborne dust to maintain visibility.

Disposal of the paint and plastic dust residue is a concern in that, although the plastic dust itself is inert, toxic elements from the paint itself may cause the residue to be considered hazardous. The cost of disposing of this dry waste is much less than wet waste but varies from region to region. Overall, the volume of waste is much smaller than for solvent stripping operations and wastewater is not generated.

The U.S. Navy compiled some comparative figures on process costs for both chemical stripping and plastic media stripping of aircraft. The figures shown in Tables 4 and 5 reveal an overall cost reduction of 48 percent compared to chemical stripping.

Industrial examples of this kind are harder to obtain, but the increasing use of plastic media blasting in industry implies economic advantages, particularly when waste disposal costs are factored in. One of the major advantages of plastic media stripping is that subsequent paint rejects on plastic media stripped parts are no higher than normal, whereas chemically stripped parts or spot-sanded parts may have higher failure rates. The cost analysis for operation of an industrial dry stripping facility is shown in Appendix A, and a model cost worksheet is shown in Appendix B.

Table 4.—Summary table of chemical stripping costs.

COST ITEM	UNITS PER PLANE	COST PER UNIT	COST PER PLANE	ANNUAL COST (150 PLANES/YEAR)
Chemicals	468 gallons	\$11.40/gal.	\$ 5,335	\$ 800,000
Labor	364 hours	\$45/hour	\$16,380	\$2,457,000
Water usage	200,000 gallons	\$0.43 per 1,000 gal.	\$ 86	\$ 12,900
Water treatment	200,000 gallons	\$8.24 per 1,000 gal.	\$ 1,648	\$ 247,200
Hazardous waste	1,024 pounds	\$200/ton	\$ 102	\$ 15,360
Electricity			\$ 333	\$ 50,000
Maintenance			\$ 667	\$ 100,000
HVAC			\$ 1,347	\$ 202,000
		Totals	\$25,898	\$3,884,760

Source: Naval Civil Engineering Laboratory, "Economic Analysis for Recycling Plastic Media" (CR 87.001), February 1987.

Table 5.—Summary of plastic media blasting costs.

COST ITEM	UNITS PER PLANE	COST PER UNIT	COST PER PLANE	ANNUAL COST (150 PLANES/YEAR)
Plastic Media	1,500 pounds	\$1.76/pound	\$ 2,640	\$ 396,000
Non-PMB Stripping Costs			\$ 667	\$ 100,000
Labor	183 hours	\$45/hour	\$ 8,235	\$1,235,250
Hazardous Waste				
Paint Dust	200 pounds	\$260/ton	\$ 26	\$ 3,900
Spent Media	1,500 pounds	\$260/ton	\$ 195	\$ 29,250
Electricity			\$ 173	\$ 26,000
Maintenance			\$ 1,333	\$ 200,000
HVAC			\$ 47	\$ 7,000
		Totals	\$13,316	\$1,997,400

Source: Naval Civil Engineering Laboratory, "Engineering Analysis for Recycling Plastic Media" (CR 87.001), February 1987.

## **Conclusion**

Plastic media stripping offers industry a low-cost method of reclaiming valuable components and finished products, as well as an important alternative in overhaul and rebuild activities. Focus

should be on overall process cost savings available through plastic media stripping compared to alternative technologies. But the added intangible values of increased worker and environmental safety with this stripping method should also not be overlooked.

## APPENDIX A

### Analysis for Investment in a Dry Stripping Facility

<u>Cost Category</u>	<u>Start up</u>	<u>Yearly Fixed Costs</u>	<u>Variable Costs</u>
<b>Start up costs</b>			
Blast/reclaim system (1/2" nozzle)	\$19,000		
Compressor/dryer (50hp)	14,000		
Dust Collection (fans & filters)	2,000		
Blast room (16Hx18Wx40L) home built	5,000		
Installation	2,000		
Furnishings	2,000		
Rent Deposit (3 months)	3,600		
Initial media 1,500lbs @ \$2.00/lb	3,000		
Two months working capital	<u>14,393</u>		
Total investment	<u>\$64,993</u>		
 <b>Operating Expenses (Fixed)</b>			
Loan payment (\$60,000 pay back in 5 yrs @13%/yr)		\$16,382	
Rent \$1,200/month		\$14,400	
Labor (2 people @ \$10.00/hour)		41,600	
Advertising		5,000	
Insurance		3,000	
Heat & lights (\$200/month)		3,600	
Phone & office supplies (250/month)		<u>3,000</u>	
Yearly Operating Expenses		<u>\$86,982</u>	
 <b>Materials:</b>			
35 lbs. media/car @ \$2.00/lb.			\$70.00/car
masking materials			15.00/car
Utilities (used when dry stripping)			15.00/car
Waste disposal (\$125 for 55gal = approx. 8 cars)			<u>15.63/car</u>
<b>Total Variable Costs</b>			<b>\$115.63/car</b>

#### Breakeven Calculation

Average charge/car of \$350 minus \$115.63/car equals \$234.37 contribution/car.

Breakeven = fixed costs/contribution = \$86,982/\$234.37 = 371.13 cars/year.

(Based on a \$100/hour blast charge this would translate into 26 blast hours per week for a breakeven).

Capacity for two man, one shift shop is two cars per day; equals 10 cars per week


Profit before taxes for one shift

$$10 - 7.13 = 2.87 \text{ cars} \times \$234.37 = \$672.64/\text{week} \times 50 = \$33,632/\text{year}$$

While the above figures are realistic for setting up a dry stripping facility, they are only one example. Start-up costs can be reduced by buying used equipment.

While operating costs can vary considerably based on labor rates, higher or lower loan payments, and rent expense. If there is room for a facility in a currently used building, with labor that could be used for either business, then a breakeven point can be as low as 3 cars or 11 blast hours per week. Similarly, charging \$50 more per car lowers the breakeven point by one car per week.

## APPENDIX B

<h1>Process Cost Analysis</h1>		
Process Item	ALTERNATIVE METHOD:	
Labor for Preparation	\$	\$
Labor for Stripping / Cleaning	\$	\$
Labor for Follow-up Cleaning	\$	\$
Labor for Pre-Finishing	\$	\$
Compressed Air	\$	\$
Other Utility Costs	\$	\$
Insurance/Liability Costs	\$	\$
Downtime <i>Example: Lost Income</i>	\$	\$
Equipment Maintenance	\$	\$
Disposal of Waste	\$	\$
Material Usage (Total Process)	\$	\$
Subsequent Failures <i>Example: Corrosion of paint</i>	\$	\$
Miscellaneous "Down-Time"	\$	\$
Minimum Parts Inventory	\$	\$
<p><b>NOTE:</b> Because plastic media stripping has been shown to <i>reduce</i> down-time in overhauling many types of vehicle parts and components, the <i>number</i> required in inventory can be reduced, reducing capital expenditures.</p>		
<b>TOTAL PROCESS COSTS</b>	\$	\$
<b>INTANGIBLE COSTS</b>	<ul style="list-style-type: none"> <li>▶ Risk to workers</li> <li>▶ Risk to environment</li> <li>▶ Miscellaneous liability</li> <li>▶ Worker morale</li> <li>▶ Customer satisfaction</li> <li>▶ Community relations</li> </ul>	

# Ultra High-pressure Water for Paint Removal in the Original Equipment Manufacturing Sector

**Al Hirsch**

*Flow International  
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## Introduction

New restrictions on the use of paint removers containing methylene chloride mandated under the 1990 amendments to the Clean Air Act are forcing manufacturers in the original equipment sector to explore alternative methods for removing paint from metallic surfaces. Some of the new techniques involve less toxic solvents, acid, sand blasting, and application of heat.

The use of ultra high-pressure water to remove hard, tough coatings from metallic substrates without damaging the surface is one of the more effective new paint removal processes. Given the present concern for the environment and need to keep costs down, there are a number of reasons why ultra high-pressure water is becoming the "tool of choice" in many material removing/stripping tasks:

- **Low volume of effluent:** A relatively low amount of water is required vis a vis the volume of material to be removed.
- **Easy separation of material:** In most cases, simple settling tanks will separate the water from the paint or other substance removed; the water can then be disposed of through the public sewage treatment system.
- **No toxic or hazardous wastes:** The process produces no toxic, hazardous, or flammable substances that require special handling.

- **No sand and/or dust:** Sand blasting requires large volumes of material to be disposed of, particularly where used on modern paint systems. Also, it is difficult to separate the sand from the material removed, and airborne dust and silt can block waterways.
- **Low energy costs:** Ultra high-pressure water does not require large energy costs (gas or electric) or extensive maintenance.

The process involves a stream of water pressurized to 35,000 psi for hand-held applications, or 55,000 psi if robotics are used. The paint is removed via energy generated by the stream, which moves at a rate of 2,280-2,860 feet per second. The technology can accurately be described as the "razor blade" of the water-blasting industry.

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## Equipment

The following pieces of equipment are necessary for the process:

- **Pump:** The process uses an intensifier-based pumping system that converts mechanical energy into oil hydraulic energy into water hydraulic energy, i.e., ultra high-pressure water. Diesel or electric-driven Jetpacs manufactured by Flow International deliver .8 to 5.6 gpm of water at 35,000 psi.

- **Hose:** The required hose has an inside diameter of 4 mm, with a working pressure of 35,000 psi and a burst pressure of 100,000 psi.
- **Tools:** Tools can be hand-held devices called Jetlances, which are equipped with rotating, multiple jet tips; alternatively, mechanized devices designed for robotic integration can be used.

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## Applications

One of the most important applications of the ultra high-pressure water blasting method is the cleaning of car carriers that are coated with multiple layers of polyurethane paint. If not removed, layers build up, flake off, and attach themselves to fresh paint on car bodies, causing costly damage. Current methods of removal include low-pressure, high-volume water blasting, gas or electric ovens, solvent baths, and hand chipping. Ultra high-pressure water is currently being used as an alternative in seven General Motors and 10 Korean car plants.

Another application is the removal of modern polyurethane or epoxy-based hull paints from ships. This technique has also been used to remove contaminated paint and thin layers of concrete in nuclear facilities, hard rubber lining from storage tanks and metal rollers, hard deposits from boiler and heat exchanger tubes, and ceramic and base coats from jet engine components that currently require sand blasting, acids, and solvents.

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## Potential Hazards

Water poses few of the safety and environmental hazards found in other solvents and cleaners. It is "inert," a known quantity, and can be easily separated from toxic or nontoxic solids after removal. However, training operators for safe application is important since ultra high-pressure water removal *cuts like a razor*, due to its low thrust as a result of the low volume of water.

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## Effectiveness

The "harder" the coating the more effective ultra high-power water will be in removing it, provided the substrate can handle the high-energy density of the water jets. The process is effective on some ceramic coating, epoxies, polyurethanes, lacquers,

flame and plasma sprayed metals, some fusion bonded coatings, and hard rubber. Soft, tacky, jelly-like coatings do not lend themselves to removal with ultra high-pressure water. However, low-pressure, high-volume water blasting can be an effective stripping method with these products.

Steel and equivalent substrates pose no problems with the ultra high-pressure water system. For aluminum, pressure, stand-off distance, and jet dwell time become critical because the ultra high-pressure water system does have the energy density to remove that metal, thereby damaging the substrate. Ultra high-pressure fan jets can be an effective stripping method provided no hot spots are present in the fan. In general, ultra high-pressure water is not appropriate for use on wood, plastic, and composite substrates because the high-energy density will attack these substrates.

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## Stripping Time

It is difficult to estimate stripping time exactly because of variables such as flow rate, pressure, number and rotation speed of jets, jet configuration, dwell time, stand-off distance, thickness of material, and operator proficiency.

Approximate estimates are as follows:

- Polyurethane-based paint on steel substrate, 5-10 mils thick: 100-120 sq.ft./hr. using 2.8 gpm ultra high-pressure water at 35,000 psi.
- Polyurethane-based paint on steel substrate, 15-20 mils thick: 30-100 sq. ft./hr. using 2.8 gpm ultra high-pressure water at 35,000 psi.
- Arcor S30, 50-250 mils thick, on steel substrate: 120 sq. ft./hr. using 2.8 gpm at 35,000 psi.
- Commercial paint removal from concrete substrate: 50-80 sq. ft./hr. using 2.8 gpm at 35,000 psi.

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## Costs

The capital costs for a Flow International ultra high-pressure water system are:

- **Pump:** (Model 40EDX, 75 HP, electric driven, 2.4 gpm at 35,000 psi): \$76,500.
- **Hose:** (50 ft., 35,000 psi working pressure, 100,000 psi burst pressure): \$1,325.

■ **Tool:** (Model 5050 Jetlance): \$7,800.

■ **Total:** \$85,625

Operating costs are:

■ **Pump:** \$4 to \$5 per hr.

■ **Hose:** \$2 per hr.

■ **Jetlance:** \$2 per hr.

■ **Total:** \$8 to \$9 per hour.

Costs for water, electricity, waste disposal, and labor are not included.

The ultra high-pressure water system is clearly a cost-effective, viable approach to paint removal that can replace methylene chloride compounds presently used for these tasks in a variety of applications.

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# **ORIGINAL EQUIPMENT MANUFACTURING**

## ***Exposure Control & Pollution Prevention***

**Chair:** Christine Whittaker  
*Office of Risk Reduction Technology  
Health Standards Division  
U.S. Occupational Safety and Health Administration*

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# Practical VOC Reduction

**Thaddeus J. Fortin**

*Haas Corporation*

*Philadelphia, Pennsylvania*

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## Introduction

Reducing volatile organic compounds (VOC) is a concern of every company that paints. Amendments to the Clean Air Act are forcing companies to change their processes to accommodate VOC reduction. Practical VOC reduction in paint shop maintenance is attainable without incurring added costs.

There are many economical ways to reduce VOC emissions from maintenance without making major changes to the painting process. Reduction in the volume of solvent-based stripper used, substitution of nonsolvent chemical products to replace stripper, nonchemical substitutions of stripper, and mechanical substitution for stripper are four practical ways to reduce VOC emissions without sacrificing quality, costs, or manpower. A brief explanation of each method follows.

### **Volume Reduction**

The most immediate and obvious way to reduce VOC emissions in maintenance is to simply reduce the amount of stripper used. Many original equipment manufacturing (OEM) companies are still using low-viscosity strippers such as paint thinner, purge cleaners, and solvent blends. These products usually contain high amounts of flammable chemicals such as methyl ethyl ketone and toluene/xylene. The use of thixotropic paint strippers, which are usually combustible, offer immediate and significant VOC reduction. The lower evaporation rate of these products, combined with the ability to cling to a surface and work over a period of time, can result in VOC reductions of 25 to 75 percent.

### **Advantages**

- immediate VOC reduction of 25 to 75 percent
- replace flammable product with combustible product
- reduce worker exposure
- reduce chemical usage, storage, and handling
- rinsable with water vs. wipe on/wipe off
- significant cost savings in labor, chemical, and auxiliary products

### **Disadvantages**

- change in maintenance process

Figure 1.—Thixotropic strippers.

### **Water-based Products**

Thixotropic strippers can effectively reduce VOC emissions caused by solvent cleaning. The use of water-based protective products in this application can all but eliminate VOC. Water-based products can be used in conjunction with strippers or as a complete substitute.

In small spray booths or booths with small-volume waterfall systems, water-based peelable coatings can be applied to walls, windows, and equipment. These products are available in white or clear and, because they are water based, they do not have a flash point. Solvent-based peelables should not be used.

In large volume water-washing booths, steel and glass walls can be covered with water-rinsable coatings as a barrier against paint overspray. Like peelable coatings, these products are water based and contain little if any VOC. They also have no flash point. Water-rinsable coatings are applied by spray or brush and used in conjunction with strippers in areas where heavy overspray buildup occurs or as a substitute for solvent strippers. VOC reduction is usually 20 to 100 percent.

Several OEM companies spray paint stripper on their grates to remove paint buildup. This is a most ineffective and wasteful way to clean grates, since these structures have very little horizontal surface area. In fact, less than 25 percent of the booth floor area is solid surface. This means that more VOC-laden stripper is wasted than is actually used. Another method of grate cleaning is to replace the painted grates with an alternate set and then clean the first set by immersion into caustic or solvents. However, an effective water-rinsable grate coating is more efficient.

Grate coatings are usually white thixotropic materials, designed to cling to the grates and to form a durable, nonchalking barrier against paint. Good grate coatings usually dry in 15 to 30 minutes to eliminate tracking and are removed by mechanical high-pressure water. Again, because they are water-based materials, they do not contain VOC and do not have a flash point.

An emerging method of reducing VOC emissions is the use of water-based, or non-VOC strippers. Although still in early stages of development, such products may offer another alternative where strippers must be used. Solvent strippers have so far not been superseded in all applications, but in certain areas water-based strippers are effective. These areas include automotive paint facilities where production is high but overspray volume is low. These products need to be carefully formulated so as not to interfere with sensitive detackification programs.

### **Protective Covers**

As many large OEM paint facilities are updated with automatic spraying equipment that is sensitive to chemicals, removing the paint overspray is becoming quite a challenge. At first, solvents were used to manually wipe clean the equipment, but this process posed many problems. As a result, protective equipment covers were developed. These covers are an attractive alternative to solvent usage. Covers completely eliminate VOC while protecting the sensitive equipment. They

#### **Advantages**

- reduce BOC emissions 10 to 20 percent
- replace combustible solvents with water
- health and safety
- excellent rinsability
- right product for the job
- collects airborne particles
- aesthetically pleasing

#### **Disadvantages**

- change in maintenance process
- may require additional stripper
- paint detackification sensitivity
- added product(s)

Figure 2.—Water-based products.

come in many sizes, materials, and designs and can be disposable or washable. The covers last days or even weeks, and cost savings in chemical usage and manpower are substantial.

#### **Advantages**

- VOC reduction up to 100 percent
- no chemical use
- no worker exposure
- helps paint detackification
- disposable/washable
- equipment longevity
- significant costs savings in labor, chemical, preventive maintenance, equipment longevity

#### **Disadvantages**

- change in maintenance process

Figure 3.—Protective covers.

### **Mechanical Reduction**

Mechanical methods of VOC reduction are also becoming popular. This alternative requires a capital expenditure; however, the technology is efficient and, in many cases, an overall cost savings can be achieved. From a safety point of view, this method is often preferable to solvent dip

tanks to strip small parts, racks, or grates. VOC can be completely eliminated.

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## Conclusion

The amendments to the Clean Air Act and other legislation have made VOC reduction mandatory for even small companies to meet compliance regulations. Many economical alternative technologies are available to help reduce VOC in the area of paint shop maintenance. It should be remembered that each operation has different cleaning requirements. Finding the best application for a particular plant requires that all internal and external factors be taken into consideration before making a decision. Once a thorough plan is

### Advantages

- VOC reduction up to 100 percent
- no chemical use
- helps paint detackification
- possible cost savings

### Disadvantages

- capital expenditure
- worker safety precautions

Figure 4.—Mechanical substitutions.

implemented, volatile organic compounds can be reduced.

# The Sponge Jet System—Environmental Ramifications

**Bill Lynn**

*Sponge-Jet, Inc.  
Dover, New Hampshire*

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## Introduction

The Sponge Jet System was designed to offer the market an alternative method to steam cleaning or hot pressure washing. The use of an absorbent sponge as an alternative to dilution with large amounts of water to remove grease, oil, waxes, and other absorbable contaminants has proven very effective for surface cleaning from both a functional and environmental standpoint.

Since paint stripping was not the primary function the Sponge Jet System was designed to perform, we have limited experience with this application. A small company with limited funds for research and development, Sponge-Jet, Inc., can only move slowly on new procedures. Using a particulate sponge as a cleaning and stripping media opens up a lot of possibilities—and almost some impossibilities. For quite a while, it seemed impossible to find a company with enough faith in our processes to manufacture the sponge, and designing a system that would adequately propel the sponge was an extended effort. For all practical purposes, the Sponge Jet System produces a functional end result similar to all media blasters, but because this media is light and irregular, it is not possible to achieve flow in common equipment.

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## Controlling Pollution During Soft Media Blasting

Finding ways to control pollution during the paint stripping process offers some interesting challenges to the Sponge Jet System. Using a sponge introduces a flexibility that is not found in most of the other accepted paint stripping media. Since we

are a new company, we haven't unraveled all the possibilities; however, to date the Sponge Jet System has cleaned heavy motor oil from wallpaper and also stripped paint from steel, leaving an anchored pattern. The question is how to take advantage of this flexibility to control pollution while stripping paint.

Sponge media's ability to absorb and control various contaminants is one of its primary strengths. Imagine absorbing a paint spill with pulverized cloth or common mineral absorbents! The Sponge Jet System propels a vast number of absorbent particles to a surface and provides great amounts of surface to absorb contaminants. If this system is used in conjunction with chemical strippers or softeners, amounts of liquid waste are greatly reduced. The sponge removes and controls both the stripping chemical and the dissolved paint in a dry operation.

Containing dissolved paint and stripping chemicals in an absorbent media is a neat trick but, for pollution control, only a step in the right direction. Separation of contaminants from the media is of paramount importance in reducing the waste stream. Most sponge media react to flushing much like a common hand sponge; however, the Sponge Jet System provides a closed rinse centrifuge system for flushing sponges. With this process, we have reduced hydrocarbons from 30 percent to less than 2 percent.

Sponge media has also removed paint without chemical assistance. Because it is manufactured, the sponge can be made to varying degrees of hardness. The sponge matrix will also hold many of the common abrasives and allow for repeated, dustless blasting at production rates somewhat slower than if the abrasives were virgin. This

ability to trap abrasives in a media that can be washed may have environmental advantages during paint stripping operations.

The absorbent nature of the sponge allows it to carry other materials to the surface. With plastic media, dust generated by the operation is greatly reduced by using a damp sponge as part of the media mix. It may also be possible to use damp sponges to clean the surface of plastic media before it is recycled.

To control dust during blasting, we have mixed damp sponge with bicarbonate. Currently, a major mineral company is working with us on a natural mineral abrasive that, in combination with sponge, will strip paint and remove grease and oils in one system. Other chemicals can be added to the sponge, including neutralizers to reduce pH readings on surfaces that have been chemically stripped and substances to dissolve salts (present on many surfaces) that are mixed with abrasives to achieve one-step surface preparation and salt removal.

Additional applications for soft media blasting could include:

- **Reducing fumes from chemical strippers.** If strippers with an affinity for soft media can be formulated, the sponge could be used at very low pressures to form an absorbent barrier during the working cycle of the chemical, which then could be removed by a higher-pressure blast.
- **Digesting blasting media.** Sponge media might prove to be ideal for this technique since it could be readily salted with material to induce bacteria to feed upon it.

- **Absorbing lubricants.** Damp sponge that is frozen with carbon dioxide become more aggressive to surfaces and could be used to absorb grease and oils, presently moved from one surface to another through dry ice technology.

- **Separating contaminants from media.** Sponge has a unique ability to change particle size. Fluids cause them to swell; conversely, introduction of a vacuum will compact them. These characteristics may prove useful in separating paint and other toxics from media.

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## Conclusions

The Sponge Jet System could be a positive environmental tool to use in paint stripping. Its flexibility makes it a possible player in combination with chemicals and other media; its ability to absorb and control contaminants and flush them easily holds much promise; and its ability to carry to the surface a wide array of impregnated liquids could prove useful. Finally, it is now possible to engineer a more abrasive sponge.

Sponge jetting is the new kid on the block, waiting to find where it belongs in the paint stripping industry. Enterprising minds hopefully will take advantage of its unique capabilities and provide the industry with another tool to bring paint stripping functions and environmental controls closer together.

We at Sponge-Jet, Inc., welcome any ideas from or joint efforts with the more experienced, knowledgeable players in the industry.

# Recycling Methylene Chloride: Optimizing the Waste Stream

**Peter R. Morton**

*Romic Chemical Corporation  
East Palo Alto, California*

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## Introduction

There is a definite and well-defined movement toward hazardous waste minimization. The Federal government has made a conspicuous and well publicized commitment to reduce pollution, and a process has been established to ensure that industry will maintain a healthy and clean environment. Industry must now respond by reducing hazardous waste or face legislation that imposes stiff fines, felony jail sentences and, in the process, negative publicity on the violators.

In the face of this potentially adversarial relationship, some companies are reaching for positive change and implementing successful waste minimization programs. Under such acronyms as WRAP (Waste Reduction Always Pays—DOW Chemical Company) and SMART (Save Money and Reduce Toxics—Chevron Corporation), these and other programs have reportedly realized a better than 80 percent reduction in solvent acquisition and a maximum of 135 percent return on their investment. Indeed, Romic Chemical Corporation also instituted an award-winning conservation program.

These conservation programs demonstrate investments in new equipment generate savings in disposal costs and acquisition of virgin solvents that often pay back investments in less than a year. This is a challenge to the supposition that company profits and federal legislation conflict. Arguably, only larger companies can profitably invest in expensive recycling equipment. However, the smaller firms can benefit from the methods used to support these procurements.

## Waste Minimization Strategies

There is no single method for reducing wastes—no magic bullet, black box, or mystical additive. Effective waste minimization programs begin with a comprehensive understanding of the manufacturing process: its limitations and tolerances, the waste produced, and its composition and properties. Only after the analysis is completed and compared to current waste disposal alternatives will industry realize meaningful options.

The solution is often as complex and multidisciplinary as it is simple. Waste minimization requires concerted effort from top management to the basic employee, who is the vehicle for any conservation policy. However, the best plans use a coordinated effort that involves the engineering, production, maintenance, environmental, and analytical departments. To conserve resources, the informed industrial company will use the following waste handling hierarchy:

- Source reduction,
- Reclamation,
- Reuse, and
- Disposal.

## Source Reduction

The ultimate goal of source reduction is to produce less waste. This is accomplished through

- Process modifications,

- Efficient use of cleanup solvents, and
- Solvent substitution.

Industry can achieve reductions by modifying manufacturing processes to use solvents more effectively or by cleaning process equipment less frequently. By defining what "clean" equipment means, a company can determine how much solvent does the job and order cleaning events to use solvent efficiently.

Another way to reduce waste is to change to a more effective solvent. New limits on VOC emissions and other legislation have forced reevaluation of many solvent processes and resulted in solvent substitutions. Regulation-motivated substitution may not reduce wastes; however, it can reduce total toxic organic emissions.

Some alternatives were explored in an EPA report, "Evaluation of Alternatives to Toxic Organic Paint Strippers," by W.J. Hahn and P.O. Werschulz (EPA/600/S2-86/063, September 1986). This study compared and contrasted the effectiveness of various commercially available paint stripper formulations that could lower total toxic organic emissions. The results confirmed that, under certain conditions, methylene chloride-free strippers could be used. Another benefit not mentioned by the authors is potential reduction of incinerable wastes. For example, the substitution of a combustible solvent (such as toluene, isopropanol, or *N*-methyl pyrrolidone) for methylene chloride frequently alleviates any need for incineration. Additionally, the reclamation potential of methylene chloride is not affected when the cosolvent is carefully chosen.

## Reclamation

The intent of the Resource Conservation and Recovery Act is to reduce waste and encourage recycling. Recycling has several benefits: it minimizes wastes requiring disposal, thereby minimizing liabilities, and conserves resources. Through recycling, the reclaimed solvent becomes a usable product, no longer a waste. Most industrial solvents are derived from crude oil, a nonrenewable resource. The energy requirements for recycling are a fraction of those required for producing virgin solvent.

Flexibility in recycling capabilities allows reclaimed solvents to meet manufacturing specifications as stringent as those for virgin solvent, depending upon the application. Recycling can be accomplished on-site (at the generators facility) or off-site at permitted treatment storage

disposal facilities. General factors influencing the recycling process are:

- Market value of the virgin solvent,
- Ease of separation (this can be complicated by lack of segregation during the waste generation process),
- Yield,
- Viscosity,
- Cost of other disposal options, and
- Halogen and fuel value.

When recycling methylene chloride, the typical waste stream is high in halogen and low in fuel value.

Advantages of on-site reclamation are better quality control and a reduction in liabilities and costs associated with waste transportation. However, on-site reclamation is effective only if a company has use for the reclaimed solvents. Additionally, high volumes are necessary to justify the cost of purchasing, operating, and maintaining recycling equipment. Off-site recycling facilities offer the following advantages:

- Economies of scale of processing,
- Analytical support for quality assurance and control,
- Outlets for reclaimed chemicals,
- Fractionation capabilities,
- Technical support, and
- Ability to blend by-products to obtain the most cost-effective method for disposal.

There are two basic types of commercial solvent recycling. One is custom toll recycling, where spent solvents are segregated, batch processed separately to meet specifications, and then returned to the original generator. This type of processing requires a minimum quantity of solvent.

The second form involves combining similar wastes and selling the recycled product. This type of recycling is available to virtually all industries, regardless of the quantity of waste.

Common to both operations is the need to properly segregate wastes. If several different waste streams are commingled, the refined solvent

will probably not meet specifications or will require prohibitively expensive processing, leaving disposal as the only alternative. There are cases where segregation is not critical; however, in general, better segregation results in more low cost processing options.

If segregation is not possible, companies should determine which solvents are compatible with methylene chloride recycling. Romac Chemical Corporation's recycling processes tolerate a variety of cosolvents. Specifically, all water-soluble solvents (not total toxic organic solvents) with a fuel value of 10,000 BTU lb<sup>-1</sup> mixed with methylene chloride have processed smoothly. Even nonwater-soluble solvents are fine—if they have fuel value, they don't form an azeotrope with methylene chloride and distill at different temperatures (again, not toxic organics).

This may appear to be restrictive, but it is not. There is only one exception—hexane—and even it can be processed, although with difficulty. The problem compounds contain halogens. Notably, chlorofluorocarbon-113 (CFC-113), which can render methylene chloride waste streams non-recyclable. CFC-113 and methylene chloride form an azeotrope for which no published method of separation exists. This azeotrope (called TMC) has uses of its own, but they are more limited. Additionally, chlorofluorocarbons of many types are being phased out as known ozone depleters. If CFC-113 must be used, segregate the stream.

## Reuse

One effective method to minimize waste is to reuse it as a product in a process or as a solvent in a less critical application.

Several paint and coating manufacturers report applications that use solvents efficiently. One successful method is reuse of wash solvents in an initial rinse, followed by a clean solvent rinse. An example is reusing solvents from an ultrapure degreasing operation as a first wash in a cascading application, allowing several reuse cycles. In another method, waste solvents collected in 55-gallon drums settle for several days. The decanted solvent is used to clean noncritical equipment like spatulas. This process, repeated until no useful solvent remains, is superior to the first method but requires more storage space. While both methods reduce the volume of waste, the waste produced is dirtier and sludgier.

If reuse is not possible on-site, companies can use a waste exchange service. Contact the U.S.

Environmental Protection Agency for more information about these businesses. Unless your waste has significant value and is not heavily contaminated, you will be wasting your time trying to use an exchange program.

The most common method of reuse is to blend wastes to meet fuel specifications for cement kilns. Cement companies set specifications for the supplemental fuel they blend with conventional fuels for ovens used in cement manufacturing. This process is extremely effective and operates in a manner very similar to rotary destructive incinerators, but it does not produce a hazardous ash.

Depending upon the nature of the waste stream, solvent recyclers use a variety of processing techniques to render waste amendable as an alternative fuel. They include:

- Distillation, to allow for the removal of unwanted chemicals such as halogenated compounds,
- Blending, to adjust the BTU value and viscosity, and
- Liquefaction, to suspend solids in solution so they behave as liquids.

Clearly, for methylene chloride waste streams, distillation allows for recycling. Blending of remaining fuel-value solvents yields the alternate cement kiln fuel. Also, since waste minimization techniques result in more sludge, liquefaction will suspend the solids for future blending. Each of the processes are joined by the necessity to have quality control measures that are achieved through extensive analytical testing. When processing waste, companies must have laboratory support not only to understand what they are processing but also to know the spectrum of products the processing will yield.

## Disposal

Wastes that cannot be recycled or reused are sent for treatment and/or disposal. The most common options include landfilling, deep-well injection, chemical treatment, biological treatment, and incineration. However, these technologies deplete natural resources.

Liability is often the driving force behind a waste management method, therefore incineration is often the technology of choice. However, with better management, wastes could be handled by recycling or reuse methods.

## **Conclusion**

The underlying forces behind hazardous waste reduction—legislation and the price of disposal—will continue to be the main motivators in the development of waste management strategies. Recent environmental regulations are dictating a new climate for resource conservation. To remain viable in the highly competitive international market, industry must continue to reexamine waste management practices and strive to reduce costs and liabilities.

By recycling solvents and employing alternate fuel production, we are conserving natural resources and lessening our dependence on foreign oil imports, positively affecting the balance of payments. Romic Chemical Corporation and other members of the National Association of Chemical Recyclers have worked to develop effective waste management strategies to handle the recovery problems of the nineties. If industry can have a functional means of handling solvent waste, we can all move toward a cleaner, more pristine environment.

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# ORIGINAL EQUIPMENT MANUFACTURING

## Questions & Discussion

**O**pening sessions in the Original Equipment Manufacturing section provided an overview of applications for paint stripping in specific manufacturing industries. Following a presentation by Jack Davis of General Motors' Truck and Bus Division in Flint, Michigan, participants discussed in more detail particular issues related to the cleaning of paint overspray in spray booths used by the automotive manufacturing industry. Questions also focused on the development of new coatings for automotive finishes and the possibility of formulating coatings that are more easily stripped by available means. John Grainger, who presented information on reject stripping in the metal finishing industry, was asked about the specific composition of certain semi-aqueous strippers being used in that sector.

Later sessions included descriptions of substitute, non-methylene chloride solvents and non-solvent technologies available for industrial paint stripping. Discussion in these sessions addressed some of the specific details of the technologies and formulations and their relevant applications to manufacturing industries.

Christine Whittaker, chairperson for the OEM sessions, asked about the range of part sizes that could be stripped using the cryogenic coating removal system. Ashok Mathur, who presented details of the system, discussed its current applications as well as the potential for the equipment to be adapted to larger parts.

For plastic media blasting, some questions focused on the parameters of the separation systems used to recover and recycle the blast media. Specifically, participants were interested in learning what remaining contamination would be found in the blast media after cyclone separation. Joe Konopka described the use of an adjustable cyclone to tailor the separating system to the grit that is being separated. Also mentioned was the availability of mechanical separation systems, which can often provide a cleaner separation than a cyclone system. This is particularly important since dust loadings in the media can reduce the strip rate.

Following the presentation on water blasting, there was additional discussion on the possibilities of adding particulate media to the water jet. It was noted that there have been applications

where media such as garnet have been added and that the result is a very aggressive or powerfully abrasive waterjet cutting tool. It was emphasized in discussion of water blasting that the technique is not appropriate for uncured, soft, or tacky paints such as those encountered in spray booth cleaning.

The use of sponge blasting for lead paint removal was discussed with regard to the potential for exposure to lead residues through air or water contamination. Participants asked about the costs of sponge blasting and the ability to recover sponges for cleaning and re-use in other blasting operations.

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# **MAINTENANCE PAINT STRIPPING**

## ***Current Paint Stripping Practices***

**Chair: James Gideon**  
*Division of Physical Sciences and Engineering*  
*National Institute for Occupational Safety and Health*

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# Paint Stripping Alternatives for Aircraft

**William D. Stevens**

*Delta Air Lines Inc.  
Atlanta, Georgia*

**I**would like to preface my remarks by noting that I speak only for the current views of Delta Air Lines, not the commercial air industry in general. I stress "current" because environmental issues and requirements pertaining to them are changing rapidly.

Delta currently operates a fleet of approximately 447 commercial aircraft that range in size from the Boeing 737 up to the latest addition to our fleet, the MD-11. We anticipate fleet size to swell to approximately 500 aircraft by the end of 1991. It is my department's responsibility to maintain the appearance of these aircraft—and uphold Delta's positive corporate image.

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## Delta's Paint Scheme

Our paint scheme covers the entire tail and fuselage of all our aircraft from approximately the wing root over the top. The airplanes' bellies are covered with bare polished aluminum. Delta uses Crown Metro's epoxy primer and polyurethane top coat system, which is electrostatically applied. This has been an extremely good system for both durability and appearance. Unfortunately, all good things come to an end. When our paint starts showing the effects of time, we must remove it.

Until recently, our policy has been to completely strip and repaint at every other paint visit (with a sanding and coating in between). Our

current philosophy is to totally strip and repaint at every paint visit, currently at four-to five-year intervals.

Polyurethane paint is a tough system to remove. Currently, Delta uses a methylene chloride-based formic acid stripper supplied by EZE Products. However, we are conscious of the environmental concerns over using methylene chloride-based strippers and have been for some time. We will continue to seek improved methods and materials to do this job opportunely, economically, and safely. To this end, we have looked at and continue to follow the development of these proposed alternatives:

- PMB blasting
- Wheat starch blasting
- Baking soda blasting
- Wet ice blasting
- Dry ice blasting
- Water blasting

We have also been looking into some water-based acid strippers that have shown increasing promise as well as the following hybrids:

- Flash lamp/CO<sub>2</sub>
- Pulse laser
- Paint softener/water blast

- Paint softener /CO<sub>2</sub> blast
- Paint softener /wheel starch blast

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## Overview of the Alternatives

### *PMB Blasting*

Delta has followed this method from its inception at Republic Air Lines in Atlanta. We have seen this method progress in military use from manual to robotic controls that lessen metal surface damage. However, even with these elaborate controls, PMB's action on the soft-clad surfaces of our aircraft skin is unacceptable.

We continue to follow developments in this process. In our opinion, PMB is not the solution because it requires precise controls and mapping time and damages the clad surface. However, Delta Air Lines does use PMB in its shops for harder alloys, castings, and steel parts.

### *Wheat Starch Blasting*

Wheat starch is relatively new on the scene, and we are following its development closely. At McClelland Air Force Base in Sacramento, California, I witnessed a demonstration using wheat starch on Delta-supplied panels. The outcome was much the same as PMB. Some panels that were taken back and blasted in a controlled environment showed more promise; therefore, we continue to work with the vendor on this method.

### *Baking Soda Blasting*

Delta has followed the baking soda process for several years in tests at our facility. It has been messy and slow and has caused sandwich corrosion problems.

### *Wet Ice Blasting*

We witnessed a demonstration of this method on one of our panels recently. After approximately five minutes of blasting, an area roughly the size of a 50-cent piece was removed. Without some assistance to soften the paint, this would not be an effective method to strip large aircraft.

### *Dry Ice/CO<sub>2</sub> Blasting*

We witnessed a DC-3 being stripped in Oshkosh, Wisconsin, and were impressed, so we invited the CO<sub>2</sub> company to Atlanta for an on-site demonstration. The CO<sub>2</sub> process shows excellent abilities to

clean soil from various surfaces and remove soft paint. During the demonstration, it proved to be very slow on our poly system. We are considering a CO<sub>2</sub> system to clean and strip aircraft wheels in an automated setting and plan to follow this system closely.

### *Water Blasting*

This system uses a hydraulic-powered, diamond-tipped rotating nozzle with 30,000 psi of water. It removed the paint but left swirls in the metal. Lufthansa is about to go into production stripping, using a water system. Based on the little I have learned, I think that this method will present some very serious control problems.

Most of the hybrid systems are at the research and development stage; we anxiously await some positive results.

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## Delta's Current Paint Stripping System

Delta continues to use the methylene chloride stripping system, which has proven fast and efficient. We do not have our head in the sand, however. Several years ago, we started a trough system to contain the stripper and stripper residues as they are removed from the aircraft. Our approach takes the following steps:

- The aircraft is docked and masked and stripper troughs are placed around it.
- The first stripper is put on the aircraft after the troughs are in place. All the stripper is removed, along with all of the paint on the aircraft's fuselage, after approximately four to six hours.
- Prior to the washdown, the stripper, along with the paint residue, is pumped out of the troughs for shipment to the chemical vendor, who tests it for possible recovery and recycling.
- We are also experimenting with the possible recovery of a quantity of methylene chloride directly from the trough system. No conclusive results have been reached yet from these tests.

Delta is now stripping aircraft in Technical Operation Center (TOC) III, our new stripping and painting facility. We have attempted to design TOC III to use today's as well as tomorrow's technology. The walls are sealed to prevent dust accumula-

tions when and if we decide to go to some type of blasting media. Also an air supply has been installed in the ceiling, as well as vent exhausts around the periphery of each bay, to give the best airflow over the surface of the aircraft during both the stripping and painting phases of the operation.

Six stacker cranes are located in the larger bay to provide access. This bay is capable of handling the largest commercial aircraft in service today. The other two smaller bays have four stacker cranes in each for access. These platforms are designed to be entirely self-contained for both stripping and painting. We intend to continue the

trough system of stripper collection in the TOC III facility and hope to fine-tune this system to the point where we will be collecting and recycling a large portion of our stripper waste.

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## **Conclusion**

Delta Air Lines is looking into the future today and planning to be ready. To this point, we are actively encouraging advancements in chemistry and paint stripping methods that will help us to perform this necessary task safely and in an environmentally sound manner.

# Media Blast Dry Paint Stripping: The Only Environmentally Safe Process

**Robert Pauli**

*Pauli & Griffin Company  
Vacaville, California*

**Charles Owens**

*United Airlines (retired)*

**C**hemical strippers and the paint they remove are major sources of hazardous waste. Conventional chemical paint strippers have methylene chloride as their major solvent and those used to remove polyurethane coatings on airplanes contain phenol. Both methylene chloride and phenol are contributors to total toxic organics (TTO) in effluent water and, as such, are hazardous wastes.

Methylene chloride is a carcinogen, and, because of its volatility, presents a severe air pollution problem. Control of methylene chloride has been addressed by the California South Coast Air Quality Management District (SCAQMD) in its Rule 1401, which requires best available control technology for toxics (T-BACT)—the most stringent emissions limitation or control technique. Methylene chloride was listed as a carcinogenic air contaminant by the California Air Resources Board in June 1990. The U.S. Environmental Protection Agency is expected to take action on this chemical by 1993. Pauli & Griffin Company maintains that the best available technology completely eliminates chemical solvents.

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## Dry Paint Stripping with Media Blast

One of the most innovative alternatives to chemical stripping is media blast dry stripping, which eliminates solvent waste and greatly reduces or eliminates hazardous waste. Any hazardous waste generated is from ingredients such as chromium, cadmium, or lead in the paint system being removed. We believe media blast dry stripping to

be the only practicable and environmentally safe alternative process because:

- Laser Stripping has not developed into a viable process for removing paint from aircraft.
- High pressure water blasting is ineffective against aerospace polyurethane coatings without first applying a chemical stripper.
- Although non-methylene chloride, non-phenolic chemical strippers may be effective when used in conjunction with high pressure water blasting or, in the future, developed to the point of working by themselves, chemicals will still be discharged into the effluent water.
- Carbon dioxide dry ice blasting releases carbon dioxide into the atmosphere, which contributes to the Greenhouse Effect. This technique also cannot remove modern aerospace coatings.
- Crystalline ice (water) blasting does not remove aerospace coatings.
- Sodium bicarbonate wet blasting can revert to sodium carbonate (soda ash) in the presence of water and heat, causing corrosion of aircraft structure. It is a messy, wet process whose effluent slurry requires separation of paint chips and occasional pH adjustment before discharge. In addition, the pH of blast slurry exceeds the manufacturer's limit for some aircraft.

- None of these alternatives is approved by the Federal Aviation Administration (FAA) or any transport airframe manufacturer, while media blasting is approved by Airbus, Boeing, Douglas, and the FAA.

## Productivity—A Case Study

Having stated that we believe media blast dry stripping to be the only environmentally safe process, the obvious remaining question is, how productive is the process? In October 1990, Lockheed Aircraft Services (LAS) Company took the military transport industry lead by using the media blast process to strip a U.S. Air Force C-130. In this case, plastic media was used. Although SCAQMD Rule 1401 initially applies to new, relocated, and modified permit units, Lockheed, as a front-runner on environmental issues, took immediate action to comply with the T-BACT provisions. Other benefits resulted from the choice to use media blasting, including:

- Stripping manhours were cut drastically.
- Aircraft downtime was cut drastically.
- The U.S. Air Force approved the job and process at first inspection.
- A thorough post-strip inspection revealed no media ingress into the airframe, as is always the case when proper masking is used.
- The South Coast Air Quality Management District was delighted with the environmental improvement and issued a process permit and its Clean Air Award to Lockheed.
- At least 60,000 gallons of water normally used and treated as wastewater were not used (and thus not treated).

Further details on this first C-130 stripping are contained in Lockheed Aircraft Service Company's *The LAS Word* (Volume 38, Number 7, October 1990). Although Lockheed did not clarify waste reduction, we estimate that this operation will generate, on a production basis, less than nine drums (55 gallons per drum) of dry waste, which will not be hazardous unless the paint being removed contains sufficient quantities of chromium, cadmium, or lead to classify the media dust as hazardous.

## Other Developments

TAT Airlines, Rodez, France, is converting to the media blasting process, and America West Airlines has used media blasting exclusively for over two years at their Phoenix, Arizona, maintenance center. In addition, the U.S. Air Force has approved media blasting on all their aircraft.

A development study for robotic applications of the process was conducted by Air Canada. Details are given in Pauli & Griffin papers "Robotic Dry Stripping of Airframes" and "Robotic Dry Stripping of Airframes: Phase II," SAE Technical Paper Series #890926. Similar robotic application studies for the U.S. Air Force are contained in Pauli & Griffin's SAE Technical Paper Series #890936, "Automated Aircraft Paint Strip Cell." Pauli & Griffin Company has worked with leading airframe manufacturers and the FAA to promote approval of the dry stripping process for commercial airlines. The company's SAE Technical Paper Series #900971, "Second Generation Airliner Dry Stripping (PMB) Following Boeing's Specification," covers processing requirements for the use of dry stripping on America West Airlines aircraft when complying with FAA and Boeing requirements.

## Composites

Media blasting is a viable process for removing paint from composites. While there is some evidence of fiber damage from this technique, the present method of hand sanding produces more damage than dry stripping.

Wright-Patterson Air Force Base research showed that hand sanding caused more damage to test panels than plastic media blasting (PMB). The Naval Air Development Center experienced less damage to the substrate from four plastic media blasting cycles than from one hand sanding operation.

## Process Control and Employee Training

The key to proper use of media blast dry stripping is process control and employee training in conjunction with the use of proper blasting equipment. Early testing of plastic media produced erroneous results because of media contamination by sand or dense metal particles. To assure clean media when using reclaimed material, Pauli & Griffin developed a dense particle separator. Details of this project are covered in our paper, "New Technology Now—Dense Particle Separator

for Dry Paint Stripping," SAE Technical Paper Series #900970. Reams of technical data have been collected to support the safety and use of plastic media. Our technical manual, one of the most complete repositories of such data, is available to interested researchers of the media blast process.

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## Conclusion

Pauli & Griffin Company is an industry leader in the manufacture of blast cleaning equipment. Our equipment is designed for use with any media: plastic, carbon dioxide, sodium bicarbonate, or starch-based. Thus, our interest is directed primarily to the equipment system and process results.

- We have rejected the use of dry ice because of its low productivity and contribution to the Greenhouse Effect.
- We are concerned that sodium bicarbonate may revert back to soda ash in the presence of water and heat and the effluent slurry mixture discharge may require a pH adjustment.
- While PMB alclad removal is within acceptable limits and surface roughness does not increase with repeated blast cycles, some commercial airlines do not want either clad removal or an increase in roughness. Wheat starch appears to be a media that will offer vast improvement in alclad removal and surface roughness. Our limited testing indicates that new wheat starch media may initially have a low strip rate but that it nears that of plastic media when it fractures.

Pauli & Griffin Company believes that media blast dry stripping is the only environmentally safe, effective, and approved (by airframe manufacturers and the FAA) process for paint removal. To provide information on the current approval status of dry stripping, we have included "A Comparison of PMB Process Specification on Airframes" as Attachment A; this is a reprint of pages 1 through 5, a chart contained in our presentation, "New Generation Dry Stripping—Major Events During the Last Year and a Comparison of USAF, Boeing, Douglas, and Airbus Process Specifications for PMB."

## ATTACHMENT A

<b>A COMPARISON OF PMB PROCESS SPECIFICATIONS ON AIRFRAMES</b>				
				<b>AIRBUS</b>
				SIL 51-007
	<b>U S AIR FORCE</b>	<b>BOEING</b>	<b>DOUGLAS</b>	1989 SEPT 6
	T. O. 1-1-8	D6-54705	CSD # 4	AIPS 02-100
	1989 SEPT 1	1988 NOV 14	1988 OCT 19	1990 JAN 30
<b>APPLICABILITY</b>	ALL AIRCRAFT	2024-T3 CLAD AL	DC-8,DC-9,C-9,	A-300, A-310
	ALCLAD AL	7075-T6 CLAD AL	MD-80,DC-10,	A-300-600
	NONCLAD AL	STEEL	KC-10A	A-320
	COMPOSITES	TITANIUM	ALCLAD AL	ALL METALS
	STEEL		ANODIZED AL	ALL COMPOSITES
	TITANIUM		STEEL	no fiber reinforced
			TITANIUM	parts coated with
				aluminum foil or
				plastic
<b>RESTRICTIONS</b>				
•NO OF PMB CYCLES	NO LIMIT	ONE, FOR NOW	FOUR	NO LIMIT
•MIN THICK AL	SEE BELOW	0.036 IN	0.050 IN	1.2 MM(0.047")
•MIN THICK STEEL/TI	SEE BELOW	NO MIN	0.050 IN	NO MIN
•MIN THICK-ALL METALS				
TYPE I MEDIA	0.016 IN			
TYPES II & V MEDIA	0.032 IN			
•ANODZD PARTS OK PMB	YES	NO	YES	YES
•REPLATE PARTS?	NOT SPEC'D	YES	YES	NOT SPEC'D
•COMPOSITES OK?	YES	NO	NO	YES
•LEAVE BASIC PRIMER?	METAL-NOT SPEC'D	NOT SPEC'D	NOT SPEC'D	YES
	COMPOS--"FLAG"			
•LEAVE ANTI-STATIC				
PAINT OR TEDLAR FOIL	NOT SPEC'D	NOT SPEC'D	NOT SPEC'D	YES
<b>FAA APPROVAL</b>	NA	YES	YES	NO
<b>MEDIA AUTHORIZED</b>	TYPES I & V	TYPES I, II, V	NO RESTRICTION	TYPE II, GRADE A
(TYPES PER MIL-P-		(NO MIL SPEC REF)		40-60 & 60-80
85891A / 0386 DD	TYPE II (if Type I			(CERTIFIED)
DRAFT OF MARCH 1990)	cannot strip 0.5			
	sq ft/min)			
<b>MEDIA NOT AUTH'IZED</b>	TYPES III & IV			

**ATTACHMENT A (continued)**

	USAF	BOEING	DOUGLAS	AIRBUS
MAXIMUM MEDIA				
CONTAMINATION LEVELS			NO MAX LEVEL.	NOT SPEC'D
•TWO-STEP METHOD			OPERATOR MUST	
HIGH DENSITY (>1.991)	0.02% (200 PPM)		HAVE DPS CAPA-	
OVERALL (>1.575)	2%(20,000PPM)		BILITY.	
•ONE-STEP METHOD		0.03% (300PPM)		
•FREQUENCY OF TESTING	LONGER OF 80 HR	MAINTAIN MEDIA		
	OR EACH ACFT	LESS THAN 0.03%		
PMB PARAMETERS ON			NO SPECIFIED	
METALLIC SURFACES			PARAMETERS. SEE	
			OPERATOR+BLAST	
NOZZLE DESIGN			PARAMETER	STRAIGHT BORE (!)
			QUALIFICATION	
NOZZLE LENGTH			TEST PROCEDURE	NOT SPEC'D
			BELOW	
NOZZLE THROAT SIZES		3/8 & 1/2 IN		8 & 16 MM
		(10 & 13 MM)		(5/16 & 5/8 IN)
MEDIA FLOW RATE				NOT SPEC'D
•3/8 IN NOZZLE		400-450 LB/HR		
•1/2 IN NOZZLE		700-800 LB/HR		
NOZZLE PRESSURE		30 +/- 5 PSI		1.5 BAR(22PSI)
•TYPE I MEDIA	40-60 PSI			MAX
•TYPES II & V MEDIA	20-30 PSI			
NOZZLE DISTANCE				150 MM(6 IN)
•TYPE I MEDIA	12-24 IN			
•TYPES II & V MEDIA	18-30 IN			
•3/8 IN NOZZLE		14-18 IN		
•1/2 IN NOZZLE		14-48 IN		
NOZZLE ANGLE		30-85 DEGREES		30-45 DEGREES
•TYPE I MEDIA	30-90 DEGREES			
•TYPES II & V MEDIA	0-80 DEGREES			
MAX ROUGHNESS, MICROINCHES		Ra = 350 μ IN		(Ra = 276 μ IN)
MAX ROUGHNESS, MICRONS		(Ra = 9 μ M)		Ra = 7 μ M
(APPROX FORMULA: MICRONS X 40 = MICROINCHES)				
PMB PARAMETERS ON	USAF	BOEING	DOUGLAS	AIRBUS
COMPOSITES				
NOZZLE PRESSURE				SAME AS AL
•TYPE I MEDIA	30-60 PSI			
•TYPES II & V MEDIA	25-40 PSI			

**ATTACHMENT A (continued)**

NOZZLE DISTANCE	12-24 IN			SAME AS AL
NOZZLE ANGLE	45-90 DEGREES			SAME AS AL
CAUTIONARY COMMENTS	USE PRIMER AS A "FLAG"			
MAX ROUGHNESS				SAME AS AL
GENERAL NOTES	PARTICLES FINER THAN 80 MESH ARE NOT DAMAGING.			TOTAL REMOVAL OF TC & P IS OK ON FASTENER HEADS
PLASTIC MEDIA REPLENISHMENT				MUST USE SAME MFGING BATCH (SIZE & GRADE)
OPERATOR TRAINING & QUALIFICATION REQ'D?	YES •THOROUGHLY TRAINED & THOROUGHLY INDOCTRINATED	YES •FORMAL TRNG •PRACTICAL TRNG •APPRENTICESHIP •9 REQMTS FOR COURSE CONTENT	YES •MUST REQUALIFY ON A REGULAR BASIS	YES •CERTIFIED OPERATORS & APPROVED TRAINING
<b>OPERATOR &amp; BLAST PARAMETER QUALIFICATION TEST PROCEDURE</b>				
	USAF	BOEING	DOUGLAS	AIRBUS
<b>OPERATOR QUALIFICATION</b>				
	YES-SEE OPERATOR TRAINING & QUALI- FICATION ABOVE	YES-SEE OPERATOR TRAINING & QUALI- FICATION ABOVE	YES-SEE THIS SECTION	YES-SEE THIS SECTION
<b>PROCESS QUALIFICATION</b>				
	NO	NO	YES-SEE THIS SECTION	YES-SEE THIS SECTION
<b>ALUMINUM TEST PROCEDURES</b>				
•ALMEN TEST STRIP MANUFACTURE				
NUMBER OF STRIPS PER OPERATOR & PROCESS			1	5
ALUMINUM ALLOY			2024-T3 NONCLAD	CLAD 7075
LENGTH X WIDTH, IN			3.00 X 0.75 IN	(3.93 X 11.8 IN)
LENGTH X WIDTH, MM			(76.2 X 19.1 MM)	100 X 300 MM
THICKNESS, IN			0.032 THICK	(0.047 IN)
THICKNESS, MM			(0.81 MM)	1.2 MM
•ALMEN STRIP PREPARATION				
MANUFACTURER PAINT SYSTEM			CONVERSION CTG	CHRMIC ACID ANDZ

**ATTACHMENT A (continued)**

			EPOXY PRIMER	BASE PRIMER
			PU TOPCOAT	WASH PRIMER
			AIR DRY	PU PRIMER
			OVEN CURE	PU TOPCOAT
				OVEN CURE
•MAX ARC HEIGHT ALLOWED, IN			0.0060 IN	(0.006 IN)
MAX ARC HEIGHT ALLOWED, MM			(0.152 MM)	0.15 MM
•MAX SURFACE ROUGHNESS ALLOWED				Ra 7 MICRONS
•FURTHER PROCESSING OF FIRST TEST STRIP				•DEGREASE
				•RECOAT WP+P+TC
				•ADHESION TEST
				•2 ADDN'L CYCLES
				STRIP & PAINT
				TOTAL 3 CYCLES
•SECOND AL TEST STRIP PROCEDURE?				YES, W/CLAD 2024
				SAME AS ABOVE
<b>OPERATOR &amp; BLAST PARAMETER QUALIFICATION TEST PROCEDURE, CONTINUED</b>				
	USAF	BOEING	DOUGLAS	AIRBUS
<b>COMPOSITE TEST PROCEDURES</b>				
•COMPOSITE TEST PANELS				
NUMBER OF PANELS PER OPERATOR & PROCESS				5
PANEL SIZE				150 X 150 MM
				(6 X 6 IN)
MATERIAL 1				CARBON/EPOXY
CONSTRUCTION 1				6 PLY
MATERIAL 2				ARAMID/EPOXY
CONSTRUCTION 2				6 PLY
MATERIAL 3				ARAMID/EPOXY
CONSTRUCTION 3				H'COMB,2 PLY/SIDE
MAX ROUGHNESS ALLOWED				SAME AS AL
<b>NON-DESTRUCTIVE TESTS</b>				
CARBON/EPOXY				ULTRASONIC
ARAMID/EPOXY				TAP TEST
FURTHER PROCESSING				•SIMILAR TO AL
				TOTAL 3 CYCLES



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# **MAINTENANCE PAINT STRIPPING**

## ***Substitute Solvent & Non-solvent Alternatives***

**Chair: James Gideon**  
*Division of Physical Sciences and Engineering  
National Institute for Occupational Safety and Health*

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# Envirostrip Starch Blast Media—A Safe, Economical Alternative to Methylene Chloride Strippers

Ruben Lenz

John Oestreich

*Ogilvie Mills Ltd.*

*Montreal, Quebec, Canada*

**E**nvirostrip is a dry blast media manufactured from a renewable resource—starch—that is processed into a crystallized form. Starch blast media is currently manufactured from high quality wheat starch in a patent-pending semi-dry process, without using chemical additives. Envirostrip blast media does not pose environmental or occupational hazards. The product is natural, nonexplosive, and does not emit an odor during use.

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## How Envirostrip is Used

Envirostrip is used in commercially available plastic media blast machines. Direct-pressure or suction type units can be used in small hand cabinets or large, walk-in facilities. When operators are removing toxic coatings in walk-in facilities, they must wear protective suits and have a proper respiratory air supply.

A clean, dry air supply for the blast stream and a metering device for media flow control are both recommended. Starch blast media has a low breakdown rate ( 5 percent) and a long life cycle; it can be used over 20 times at blast pressures up to 45 pounds per square inch (psi).

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## Aerospace Applications

Envirostrip efficiently removes many coatings in a variety of aerospace applications, including:

- Paint from fiberglass and graphite composite materials, including difficult-to-strip radomes,

- Paint from clad aluminum, anodized clad, and anodized aluminum, and
- Coating from interior aircraft materials such as sidewall panels.

The removal rate depends on the coating-substrate combination and its condition. Polyurethane paints can be removed at rates of 0.25 to 1.0 square feet a minute (sq.ft./min.) in hand cabinets and up to 2.5 sq.ft./min. in large, dry-stripping facilities.

The starch blast media achieves good productivity without compromising job quality or risking undue damage to underlying substrates—a major advantage. It is particularly effective on delicate materials such as soft metals and composites.

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## Industrial Applications

Although starch blast media was primarily designed to remove coatings from aluminum and composite materials in aerospace applications, several other industrial uses exist, including:

- Equipment cleaning, particularly where a dry method is preferred,
- Electronic deflashing, especially where electrostatic buildup on components cannot be tolerated,
- Stripping of delicate aluminum and magnesium parts, where surface etch must be avoided,
- Engine cleaning where solid abrasives must be eliminated from parts before they are returned to service,

- Surface preparation for metallic and composite materials, and
- Metal deburring and mold-cleaning.

## Disposal Methods

The waste generated with Envirostrip can be disposed of in a variety of ways. Legislation and methods for disposal depend on the toxicity of the coating being removed.

When Envirostrip is used for dry blasting, the media eventually breaks down into a dust that is removed from the work area by a cyclone device. Since the spent dust contains the coating or paint removed, the nature and toxicity of this coating will dictate disposal methods.

The quantity of spent dust generated depends on the blast pressures and the strip rates. At 25 to 35 psi nozzle pressure, approximately 0.2 to 0.4 pounds of dust are produced per square feet of surface stripped, while pressures of 35 to 45 psi produce 0.4 to 0.7 pounds.

Ogilvie Mills Ltd. recommends disposing toxic-laden dust as a fuel in cement kilns. This process provides a safe, economical method of destroying dry toxic substances. Licensed operators will pick up the toxic dry waste at a reasonable fee.

An alternative disposal method is being developed for large-scale stripping operations. Enzyme degradation of the dust can solubilize the media in water, enabling separation of the toxic paint solids through filtration, centrifugation, or settling. The technique employs a heat stable alpha-amylase enzyme and technology that is well known to the starch industry. A small concentration of enzyme ( 0.2 percent) solubilizes the media within minutes. The paint solids separated out can be disposed of as a dry toxic waste, and the remaining filtrate solution can be digested in a waste treatment plant.

This continuous process is being studied to determine whether the risk of heavy metals leaching into solution can be eliminated. Since toxic waste would be reduced by 80 to 85 percent, this is an economical disposal method.

## Economics of Starch Blast Media

The estimated total cost of stripping polyurethane or epoxy primer paint systems is \$1.87 per square foot, which represents the complete stripping of aluminum aircraft surfaces to the bare substrate (see Table 1).

Table 1.—Envirostrip stripping cost breakdown.

STRIPPING COST BREAKDOWN	COST (\$/SQ. FT.)
Media consumption	0.92
Manpower (\$30/hr)	0.50
Equipment depreciation	0.16
Disposal	0.29
Total stripping cost	1.87

Note: The above estimate is based on typical aviation coatings after three years service. Disposal cost is for toxic dry waste.

## Conclusion

Envirostrip starch blast media provides a unique process for coating removal and surface treatment. For aerospace applications, it efficiently removes polyurethane and epoxy paints from aluminum and composite surfaces and can be used in industrial applications, such as equipment cleaning, electronic deflashing, and surface preparation. Starch blast media is used with commercially available plastic media blast machines. The low breakdown rate and longevity of Envirostrip make it an economical alternative to chemical strippers.

# Crystalline Ice Blasting

**Sam Visaisouk**

*IXTAL Blast Technology Corporation  
Victoria, British Columbia, Canada*

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## Introduction

Ice blast technology was developed as a dust-free coating removal technique for confined spaces such as ship interiors and machine rooms. As research and development progressed, it was evident that the original concept was only partly correct. Scientists discovered that the non-abrasive property of ice particles produced a uniquely different effect in blasting and, as a result, some interesting implications and applications were identified.

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## Properties of Ice

As a blast medium, ice offers some important operational advantages because of some of its properties.

- Ice is not abrasive. Large ice cubes are hard and can be abrasive, while small ice crystals are not, generally. Since ice particles fracture under a high load, they can limit impact force, thereby preventing damage to delicate substrates. Ice can be used to clean and decoat systems containing different materials, such as gaskets and plastic adjacent to abrasion-resistant materials, such as steel. Here, the benefit is in reduced preparation time.
- Ice undergoes dustless deformation. Evident from the outset, this property is still important because it provides a healthy environment for workers and machines. Cleanup efforts are also reduced.

- Ice melts to water. In many decoating applications in which coating materials have known or unknown origins, the debris or waste must be contained and handled in specified procedures. Spent media—water in this case—can be easily separated from debris so that waste handling and disposal are not further burdened. Waste management involves conventional industrial filtration techniques.
- Ice is made from water. Industrial quality water is readily available in most places. Ice-making technology is well established and its cost is more than reasonable, at approximately \$6 per ton. To make ice, water and electricity are required. The cost of both are regulated, which means future media costs will be controlled as well.

---

## The Mechanism of Fracture Decoating

Since ice is not abrasive, it does not decoat by the conventional abrasive processes, as does sandblasting. While abrasive erosion technology can be very efficient, it lacks the ability to discriminate the coating material from the substrate. Figure 1 illustrates this problem.

A less dominant way to erode material is by fracturing it. Fracturing takes place when the impacting particles have sufficient energy to overcome the fracture threshold of the target. Under low impact energies, conical cracks form. As impact energies increase, radial and lateral cracks appear. The intersection of these cracks defines a

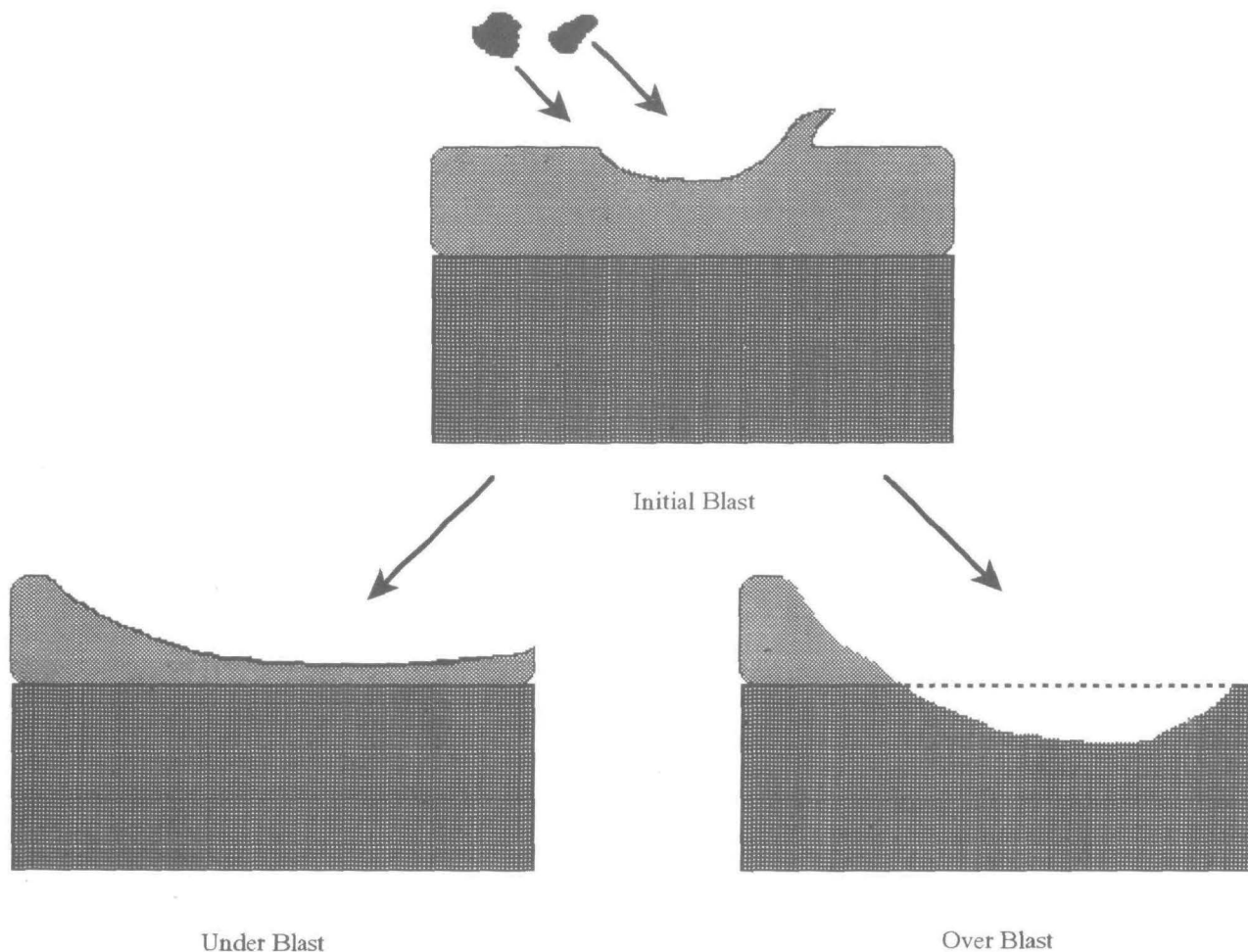


Figure 1.—Coating removal by abrasion.

volume element that is released from the material to indicate erosion, as shown in Figure 2.

To take advantage of this mode of decoating, ice particles of various sizes are used. Larger particles have sufficient energy to initiate cracks while smaller ones can only extend them. By regulating ice particle size distribution, impacting energies can also be adjusted to give optimal cracking, which leads to disbonding of large chips of coating material, as shown in Figure 3.

In addition to fracture decoating, a very efficient mechanism for decoating has been observed with ice blast. Paint chips as large as 10 by 10 centimeters have been dislodged. The theoretical and experimental bases of this effect are still being investigated.

## System Description

Ice blasting requires an ice maker, an ice-handling module, an air compressor, refrigeration, and a blast nozzle, as illustrated in Figure 4.

- Commercial ice makers are readily available. For fixed installations, ice capacity should be in the range of 200 to 400 pounds per hour per nozzle. For large installations, total ice production could go up to five tons per hour.
- Standard industrial air compressors can be used. Normal air pressures range from 70 pounds per square inch (psi) for enamel decoating to 125 psi for polyurethanes.
- A refrigeration unit is required to handle ice making, equipment cooling, and ice transport.
- The ice-handling module integrates all these units. It provides proper ice size distribution for optimal performance, precision metering to prevent ice clogging and jamming, and low energy transport to minimize ice particle attrition.

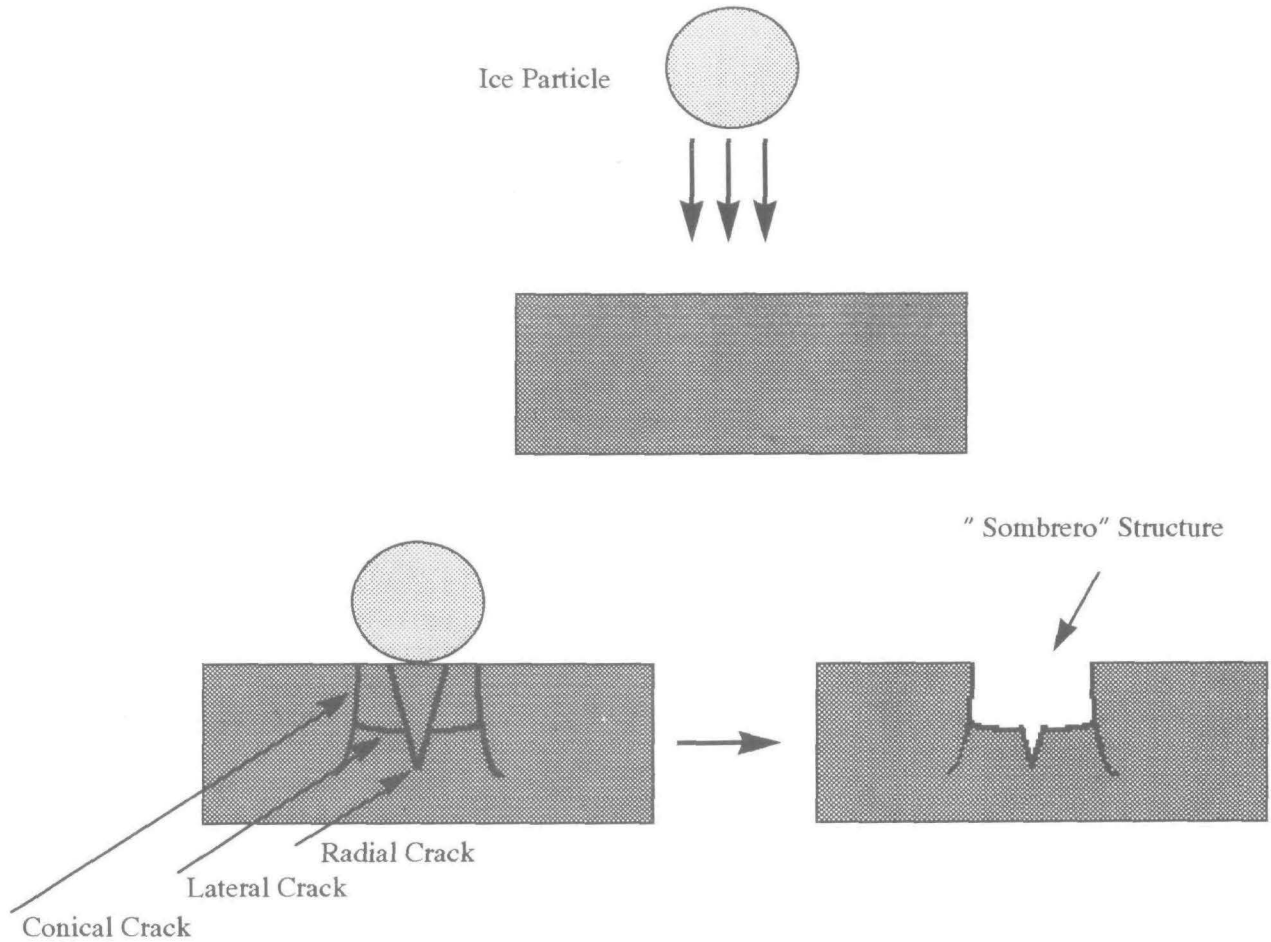


Figure 2.—Crack formation and erosion by fracture.

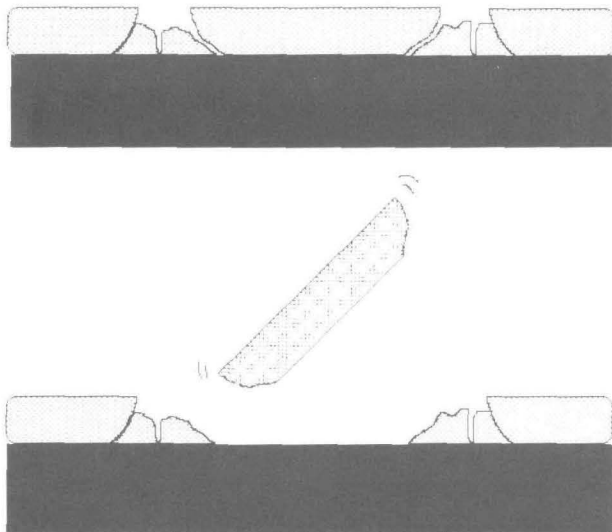


Figure 3.—Crack propagation and coating lifting.

- The blast nozzle is a proprietary design that maximizes energy transfer between the air blast stream and the ice particles.

- For mobile service, all these components—along with an air compressor and a diesel electric generator are contained in a 40-foot trailer. For normal applications, 50 feet of hose is adequate. Longer hoses can be accommodated, if required.

## Waste Management

The spent media is water, which can be readily separated from blast debris. Therefore, there is no spent media to compound disposal problems. Ice is made from water, the spent media, which makes media recycling simple, logical, and economical.

In typical operations, about 400 pounds of ice are used per hour. This translates into 40 gallons of water, of which some 20 to 40 percent evaporates during blasting, depending on weather conditions. A floor drain with a simple filtration system is all that is required in the facility. Since ice blast is dust-free, dust collection or massive ventilation systems are not needed.

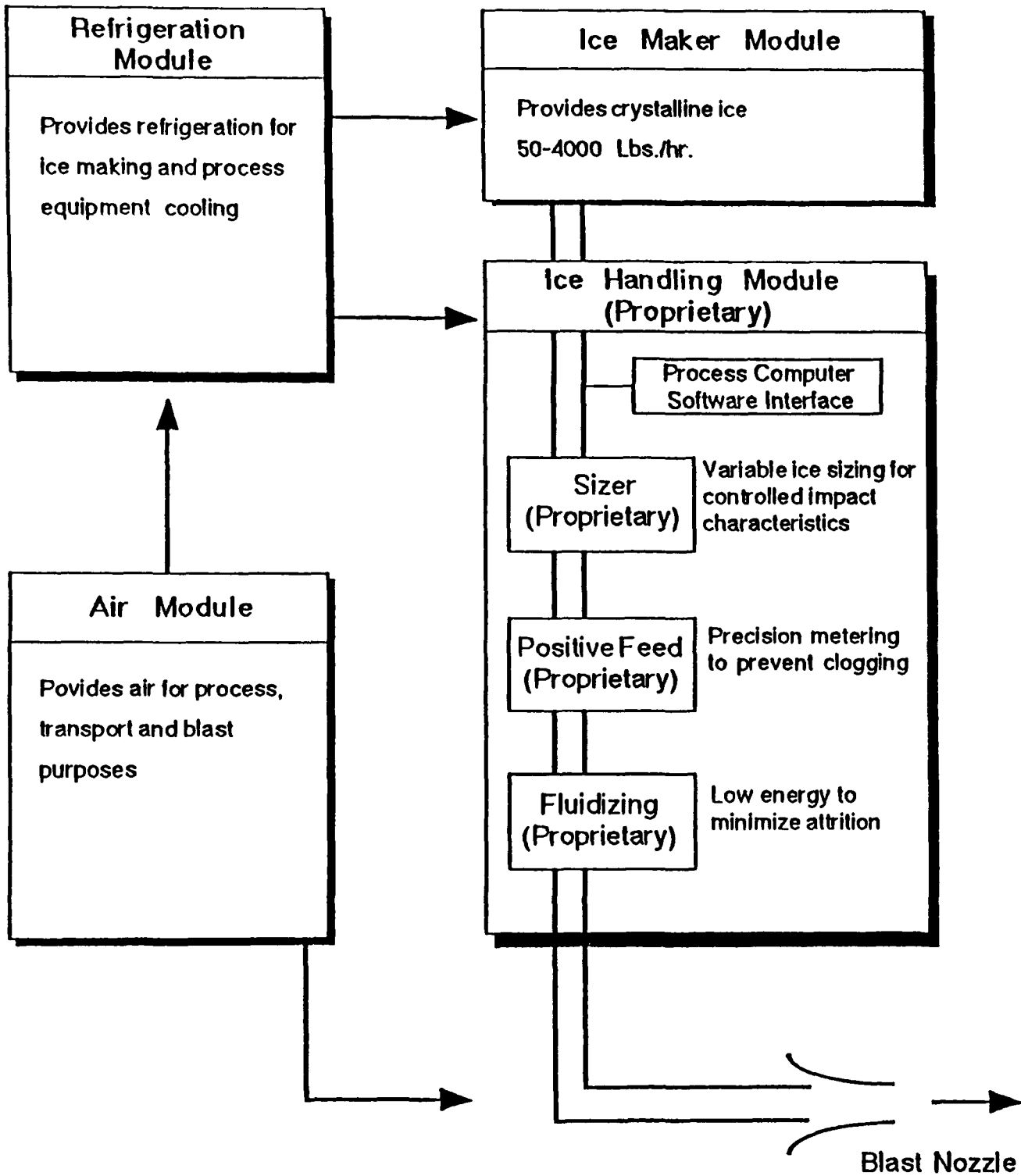


Figure 4.—The IXTAL process system.

## Conclusion

Ice blasting is not abrasive; therefore, it can be used to selectively disbond coatings from the weakest interface. In multiple coating systems and under proper operating conditions, it is possible to lift off the top coat without affecting the primer. This has been achieved with the DeSoto aircraft paint system on clad aluminum. In other decoat-

ing applications, paint removal down to bare substrate is common.

Ice blast does not damage delicate substrates such as glass, fiberglass, plastics, aluminum, and rubber gaskets. Because of this, it does not provide a white metal finish in the conventional surface preparation sense. As ice blast is a relatively new process, application and performance standards have not been established.

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The following figures provide a general overview of the performance and costs of the technology.

■ <b>Equipment description</b>	Self-contained mobile system with four nozzles and 2,000 lbs/hr ice capacity
■ <b>Equipment cost</b>	\$650,000
■ <b>Total operating cost</b>	\$25/hr
■ <b>Media cost</b>	None, included in operating cost
■ <b>Utility cost</b>	Minor amount for water
■ <b>Strip rate</b>	Polyurethane/epoxy systems: 80-100 sq. ft./hr Alkyd/enamels: 200 sq. ft./hr Epoxies: 50-150 sq. ft./hr
■ <b>Labor cost</b>	Four hours for these production rates

# ARMEX/ACCUSTRIP Bicarbonate Blasting

**Gene McDonald**

*Church & Dwight Company, Inc.  
Princeton, New Jersey*

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## Introduction

The ARMEX®/ACCUSTRIP™ process is a low impact blasting technology that is a safe, environmentally sensible and cost-effective alternative to chemical stripping techniques. The process utilizes low pressure blasting equipment—The ACCUSTRIP System,™ with a specially formulated abrasive media based on sodium bicarbonate—ARMEX® Blast Media. The ARMEX system was developed by Church & Dwight, the makers of Arm & Hammer® brand baking soda, in conjunction with Schmidt Manufacturing Co., the producer of the ACCUSTRIP equipment.

The ARMEX method has found uses in the aviation, industrial maintenance, and original equipment manufacturing (OEM) industries. It also has been used effectively on a wide range of substrates, from aircraft aluminum and composites to automotive plastics and from industrial tile work to instrument glass. The baking soda blasting system not only removes paint and other coatings but also removes grease and oil. The soft abrasive nature of ARMEX along with the precise control offered by the ACCUSTRIP equipment makes this method applicable to virtually any substrate.

Since ARMEX Blast Media is water soluble and nontoxic, waste disposal is facilitated. Sodium bicarbonate—more commonly known as baking soda—is an excellent source of alkalinity that is desirable in waste treatment operations. The paint, grease, and other foreign matter from the decoating operation are insoluble in the ARMEX solution and can be removed by using standard filter and degreasing techniques. The resulting effluent can usually go directly to the waste treatment system. The filtered paint chips and captured grease are the only potentially hazardous waste materials, thus greatly reducing the volume of toxic waste compared to chemical stripping techniques.

The ARMEX/ACCUSTRIP system also addresses worker and workplace safety issues. Because of the benign nature of the baking soda formulation, usually workers need only dust masks and face shields while working with this system. As with all blasting systems, ear protectors must be worn. The net effect is that worker and workplace safety is improved significantly over chemical stripping techniques while the cost of providing this improvement is significantly reduced.

The simple ACCUSTRIP system is not only low cost but can be easily adapted to many applications. Portable systems seem to be the most popular currently, but fixed systems also are available. Although the ACCUSTRIP is the primary system using ARMEX, with minor modifications, the baking soda formulation can be used with many systems.

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## Equipment Description

ACCUSTRIP is a modified wet blast system that uses compressed air to propel the ARMEX against the surface to be cleaned. At the nozzle, a small amount of water is added and atomized. This water reduces dust generation and, in some cases, helps cool the surface being blasted (Figs. 1 and 2).

The key to the effectiveness of the ARMEX Blast Media on the wide variety of substrates and coatings is the precise pressure and flow control of the ACCUSTRIP system. As developed, the ACCUSTRIP system allows the operator to "dial in" the key parameters appropriate for the job at hand. Continuing development will further expand the versatility of this equipment.

ACCUSTRIP comes in a variety of portable models and can be installed as a fixed system. The system is self-contained and needs only sources of compressed air and water to make it fully operational. Because the ARMEX process is a one-through wet blasting method, expensive air

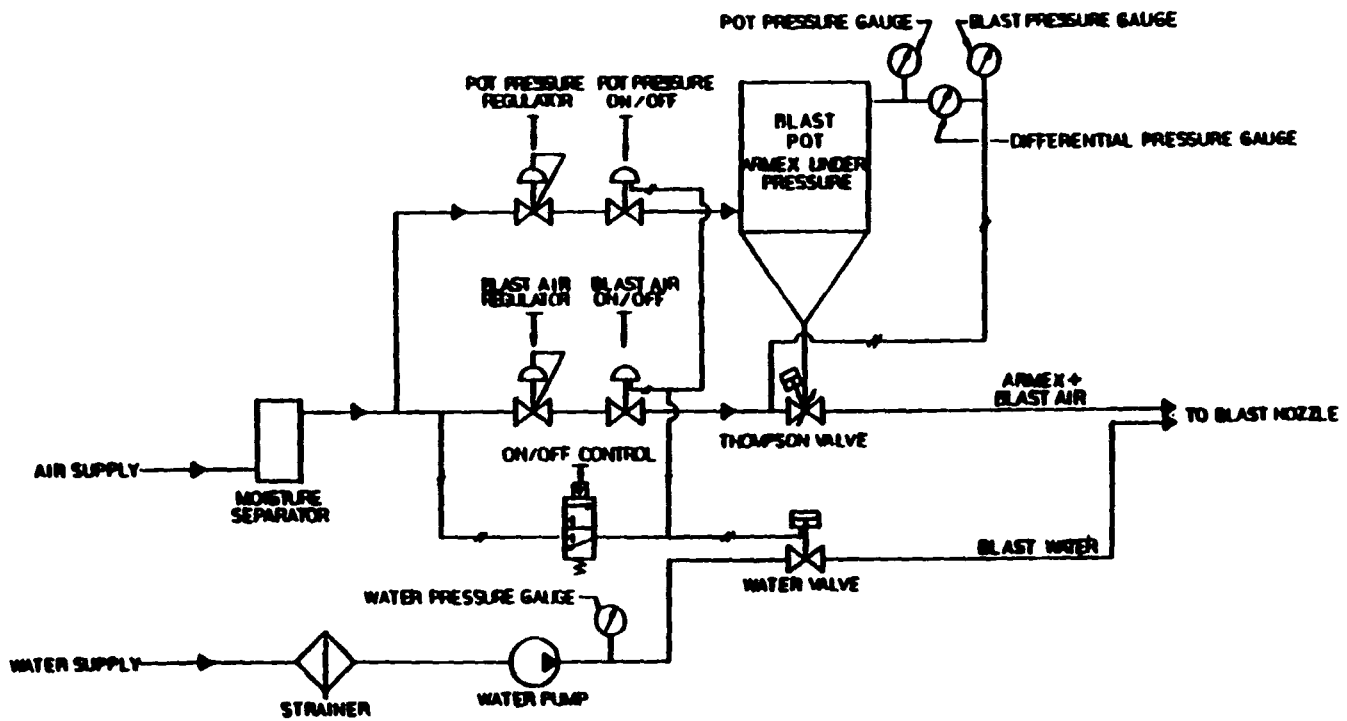


Figure 1.—ACCUSTRIP flow diagram.

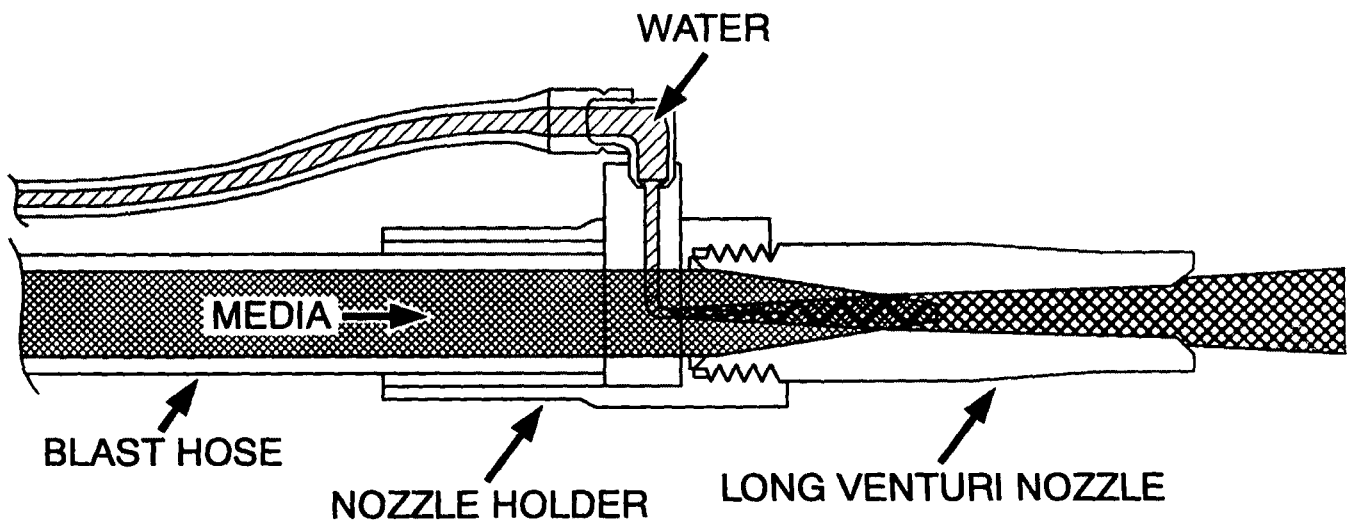


Figure 2.—ACCUSTRIP nozzle diagram.

handling, recovery, and decontamination auxiliary equipment are not necessary. The self-contained ACCUSTRIP system can be purchased for as little as \$13,000.

## Process Description

The ARMEX/ACCUSTRIP wet blast process is an adaptation of abrasive blasting technology. The ARMEX media is propelled by compressed air onto the surface to be cleaned. Nozzle pressures vary depending on the substrate type and the thickness of the coating to be removed, but normally range between 30 and 60 pounds per square inch. The media strikes the surface and disintegrates, taking

with it the coating. Water is injected into the media/air stream just prior to the venturi nozzle. This water atomizes and forms a containment core around the media, reducing dust generation. Water volume is normally less than 0.5 gallons per minute and can be supplied from a garden hose connection.

The ARMEX, water, and removed coating form a sludge that is rinsed down with water. The ARMEX media is about 10 percent soluble in water at normal temperatures. Therefore, about 10 pounds of water are needed for every pound of ARMEX to completely solubilize it. However, depending on the coating removed and the analysis of the sludge, complete solubilization may not be necessary for disposal.

Aside from the ARMEX media itself, the major difference between the ARMEX/ACCUSTRIP system and other blasting techniques is the precise flow control. Most blast systems rely on nozzle size and compressor volume to determine the flow. With the ARMEX/ACCUSTRIP system, flow can be controlled within 0.25 pounds per minute. Precise flow control is important for two reasons. First, only the amount of ARMEX that is necessary for coating removal is used. At equivalent compressed air volume and nozzle size, the ARMEX/ACCUSTRIP system uses 70 percent less media than other blast systems. Not only is this economical and environmentally sensible, but it also reduces the risk of substrate damage. Secondly, precise flow control allows for predictable and repeatable results. This is especially important when dealing with robotics systems and with extremely sensitive substrates.

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## System Performance

The ARMEX/ACCUSTRIP system has found uses in a wide variety of maintenance and OEM markets. The system's versatility is directly attributable to the nature of the ARMEX Blast Media.

Although the equipment is important, the real key to the ARMEX/ACCUSTRIP process is the media—ARMEX. Based on sodium bicarbonate (baking soda), ARMEX Blast Media is a proprietary inorganic compound (patent pending) that is made to Food and Drug Administration and U.S. pharmacopeia standards. Therefore, it is suitable for use in food plants. The granulation of the ARMEX media is precisely controlled, which allows the fine control of medium flow and performance. A series of ARMEX products (grades) have been developed to meet the varying requirements of industrial users. Combined with its soft abrasivity and non-toxic nature, the precise granulation control makes ARMEX the ideal media for many different types of decoating operations. The effects of these and other attributes on the system's performance are highlighted in the following paragraphs.

### ***Nonflammable, Nonexplosive, Nonsparking***

These features are especially important in industrial cleaning operations like petroleum refineries and petrochemical plants. The ARMEX media can be used to decoat and degrease while the plants are in operation, thus providing plant management with significant flexibility and cost avoidance in maintenance operations. Unlike organic-based blast media, the dust generated by

ARMEX is not potentially explosive. In addition, since sodium bicarbonate is a fire suppressant, the ARMEX/ACCUSTRIP system provides additional fire extinguishing capability during maintenance operations.

### ***Food Grade Product***

Maintenance operations in food processing operations are sometimes very difficult. The use of hazardous and potentially toxic materials is severely restricted. Alternatives either require considerably more maintenance time or present other decontamination problems. The availability of ARMEX, a food-grade, water-soluble decoating and degreasing system, has improved heavy maintenance operations in food products plants.

### ***Free Flowing/Precise Granulation***

ARMEX Blast Media is formulated to permit precise flow control through the ACCUSTRIP equipment. To achieve this precise flow control, the media must be free flowing under a wide range of operating conditions. This free-flowing performance characteristic along with precise granulations has permitted the ARMEX/ACCUSTRIP system to be used on some extremely intricate production line operations in the automotive OEM industry. In one automotive robotics operation, the ARMEX/ACCUSTRIP system was demonstrated to be an effective and economic alternative to methylene chloride in removing overspray and in-mold coating from composite panels. Not only did this application require precise control of the removal operation, but it also required that the system start and stop precisely during segments of the operation. The ARMEX/ACCUSTRIP system is easily adapted to meet these stringent requirements. A video depicting this application is available.

### ***Soft Abrasivity***

Although this term seems somewhat contradictory, it is an important attribute of the ARMEX Blast Media. As long as the ARMEX/ACCUSTRIP system is operated properly, ARMEX is sufficiently abrasive to remove just about any coating from a wide variety of substrates without damaging the substrate.

In industrial maintenance operations, two-part epoxy coatings over 10 mils thick have been removed from steel substrates at a rate of nearly 80 sq. ft./hr. More impressively, fusion-bonded paints over 20 mils thick have been removed from piping systems at a rate of 30 sq. ft./hr.

Polyurethane top coats and epoxy priming systems 4 to 6 mils thick have been removed from aircraft aluminum at a rate of 120 sq. ft./hr.

On steel, aluminum alloys, and other structural materials, no change to the substrate is evident. On softer metals such as clad aluminum, some anchor pattern is evident, but far less than is caused by alternative blasting techniques.

With plastics, composites, and other sensitive substrates, the soft abrasivity of ARMEX has been very effective. Coating systems removed run the gamut from acrylics to polyamides to powder coatings. From graphite epoxy aircraft composites to polyurethane RIM products in the automotive industry, economical coating removal rates have been achieved with no appreciable substrate damage. Care, however, must be taken in system operation; properly operating parameters must be established and system operators must be properly trained. For some operations robotic or semi-robotic systems are recommended.

The soft abrasive nature of ARMEX also plays a part in other aspects of industrial maintenance. Since ARMEX is softer than bearing material (phosphor bronze, etc.), bearing surfaces on rotating machinery and equipment do not have to be masked during maintenance operations when the ARMEX/ACCUSTRIIP system is used. This provides for significant prep and decontamination savings in maintenance operations. You can literally strip it off without shutting it down.

In conclusion, ARMEX is sufficiently abrasive to remove even the most difficult coating, but soft enough to not damage the most sensitive substrates if the system is operated properly. To bring the point close to home, ARMEX is similar to the sodium bicarbonate formula that dental professionals use to clean your teeth—that's soft abrasivity!

## Waste Management

The ARMEX/ACCUSTRIIP system is a once-through system, i.e., the ARMEX media is not reusable as a blasting media. This ensures that uncontaminated product is projected against the surface to be cleaned. This system also reduces overall cost by eliminating the need for recovery and reclamation equipment.

The spent ARMEX media, however, has a use in waste treatment systems. Most secondary systems are heavily acid-loaded and require alkalinity adjustment. Sodium bicarbonate, the main ingredient in ARMEX, is used commercially to provide alkalinity and pH control for both aerobic and anaerobic digester systems. Thus ARMEX, unlike

other stripping technologies, does not generate any additional hazardous waste as a result of the stripping process.

The waste generated by this process is a sludge containing spent media and the pulverized coating plus any dirt, oil, or grease that was on the surface. The typical analysis of this waste indicates that the removed materials constitute about 1 percent of the waste, while the remainder is spent media (37 percent) and water (62 percent). A maximum of 8 pounds of waste per minute per operating nozzle is generated. Since the rinse water will partially solubilize this sludge, a containment system must be in place.

In the cases where the pulverized paint or coating may represent a toxic waste, appropriate measures must be taken to handle it. Since these materials are insoluble in water and ARMEX is soluble, the potentially toxic materials can be removed by dissolving the spent media waste and filtering out the insolubles. The toxics can then be disposed of properly while the liquid effluent can normally be directed into the sanitary waste treatment system. Analysis of both the soluble and insoluble waste must be done prior to discharge or disposal to ensure that all regulations are met. Actual experience with ARMEX has shown that sewerage can be carried out in conformance with regulations.

In some cases, partial solubilization of the spent media waste is appropriate. No additional water beyond the system output of approximately 0.4 gallons per square foot of area depainted is added to the spent media.

The residue is collected and the solids—typically paint and primer chips, dirt, grease, oil, and undissolved media—are separated from the sludge by settling, centrifugation, or evaporation/drying. Actual experience has shown that sanitary landfilling may be appropriate for this solid waste. However, since coatings and conditions vary widely, the solid waste must be analyzed and compared to local and federal regulations.

With either method, the volume of true waste as compared with methylene chloride and other decoating systems is drastically reduced. Unlike some blast techniques, no pre-wash is necessary; thus coating removal and waste generation are a one-step operation.

## Economics

No description of an alternative new process would be complete without a full review of the costs. However, when blast systems are compared with chemical cleaning systems, it gets a bit like com-

paring apples and onions. The methods are so different that you are never sure you can get them to an equalized base. Further complicating the analysis are the inherent differences in coating systems and substrates. Nevertheless, since cost evaluations have to be made, we used the following rationale to determine a standard cost per square foot of coating removed:

- For blast systems, we used labor, raw materials consumed, capital, energy, and waste disposal.
- For chemical stripping, we used labor, raw materials, and waste disposal as the cost base.
- Prep costs were not included because these vary so widely, depending on the application.

The cost analysis presented in Table 1 is based on a theoretical aircraft depainting operation. It was prepared to provide the EPA with base data to compare various stripping methods.

**Table 1.—ARMEX/ACCUSTRIP cost analysis.**

Aircraft Stripping	
Labor	\$0.77/sq. ft.
Raw Materials	2.40/sq. ft.
Equipment	0.02/sq. ft.
Energy	0.03/sq. ft.
Water	0.27/sq. ft.
Waste Disposal	0.02/sq. ft.
Total Cost	\$3.51/sq. ft.

For other maintenance operations, the costs will be much lower because of the cost of raw materials—the aircraft grade of ARMEX is a

premium product because of stringent aviation requirements. The use of Maintenance Formula ARMEX would reduce raw material cost to about \$1.50/sq. ft. and also should improve the labor costs.

Although comparisons are difficult, Table 2 provides the results of an evaluation conducted by ICF in 1989 on the various stripping methods. As you can see the ARMEX method is appreciably less expensive.

**Table 2.—Cost comparison of stripping activities.<sup>a</sup>**

TECHNOLOGY	ICF ESTIMATE (\$/LB OF MC) <sup>b</sup>
Methylene Chloride	2.05
Plastic Media Blasting	2.61
ARMEX Blasting	1.89

<sup>a</sup>Costs are compared for the military aircraft submarket of the maintenance paint stripping market.

<sup>b</sup>The sodium bicarbonate estimate was developed in \$/sq. ft. and converted to \$/lb. of methylene chloride replaced using the methodology presented in the ICF's analysis.

## Conclusion

The ARMEX/ACCUSTRIP system is a safe, effective, and ecologically sensible system, a viable alternative to chemical stripping methods for a wide variety of maintenance and OEM applications. The system has found uses in applications as varied as winery maintenance and petrochemical plant maintenance. It has been used to strip substrates as delicate as aircraft wing composites and the Statue of Liberty to substrates as substantial as submarine hulls and office buildings. It has even been used to strip dinosaur bones!

# The Good, the Bad, and the Ugly—But, for a Few Dollars More...

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**F**ew people in the past envisioned that chemical stripping agents would one day be called "caustic" or "toxic" and would create so much concern with organizations known as the U.S. Environmental Protection Agency (EPA) and the Occupational Safety and Health Administration (OSHA). Paint residues, along with chemical stripping agents, were once dumped in local ditches, landfills, deserts, or wooded areas. Once it was discovered that these chemical agents could be harmful to both personnel and the environment, efforts were made to eliminate chemical stripping from the aviation industry.

Now that there is a worldwide effort to eliminate chemical stripping, numerous new processes have been investigated. All too often, technicians convince management personnel that any form of alternate stripping will severely damage aircraft, while sales personnel demonstrate equipment to potential customers and claim no damage to aviation substrates. If chemical stripping had received the in-depth investigation to which new alternate methods of stripping have been subjected, chemicals would never have been used on aviation surfaces.

Everyone wants to resolve the aviation stripping issue one way or another. Management wants a fast, cheap operation that will satisfy local environmental officials and OSHA. On the other hand, the technicians are looking for minor effects that can be classified as "damage." However, most of these technicians know little about the real world of aviation and the types of true damage that aviation skins sustain daily. Sales personnel want their equipment to be superior and to be known for solving all problems.

They, like management, are driven by the profit motive. This report covers all present methods of stripping and evaluates the benefits and drawbacks of each. The report concludes with a recommendation for a method of stripping that meets all parameters for both composite and metal aviation substrates and eliminates toxic waste streams and landfill material.

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## Chemical Stripping

Damage sustained during the chemical stripping process has been overlooked as an explanation for the cracking of aviation skins. As modern primers and paints have become tougher to remove, the chemicals have become stronger. The phenolic and formic acid-based strippers create hydrogen embrittlement to the skins and make them susceptible to cracking.

Any stripper that seeps under skin laps or into joints and is not completely neutralized with water can readily cause corrosion and cracking. Usually, this type of corrosion is not visible until substantial damage has occurred. Acid strippers that seep into an electrical wire bundle or flight control cable/rod may set the stage for a possible midair emergency. Yet, most commercial carrier airlines do not neutralize with water because of the high volume of toxic waste produced and the cost of cleaning the water. Instead, the acid residue is just scraped off the aircraft and sent for disposal. About 90 percent of all accidents involving spills occur during this transportation phase.

Incineration costs \$750-\$1,200 per 55-gallon drum. The waste generator is responsible "cradle

to grave" for this "toxic goo." Landfill of methylene chloride is no longer permitted. Accumulated paint and primer around rivet heads and in low spots the chemical stripper did not reach are abraded with rotary sanding discs, wire brushes, steel wool, or Scotchbrite pads. This creates skin friction heating, gouges, and minute ruptures; it also removes corrosion protection and reduces metal from skin and rivet heads. The steel wool hairs imbed and create galvanic corrosion. Scotchbrite pads cause Alclad smearing and crack covering. All this action decreases strength, increases corrosion susceptibility, and creates crack initiation sites. Stress corrosion cracking, filiform corrosion, galvanic corrosion, and intergranular corrosion can result. Abrasion (wools, Scotchbrite, sanding pads) also removes Alclad, anodize, and ion vapor deposited (IVD) protective metals on fasteners.

Users may continue to chemically strip in lieu of a blasting type strip operation out of concern that the soft Alclad top layer may be peened over a skin crack and thus mask detection (crack healing). However, it should be noted that chemically stripped aircraft are usually "rubbed down" with abrasive pads such as Scotchbrite to remove any paint nubs or deposits. This process is very effective, but it also smears the Alclad layer, dramatically masking cracks. Steel wools may also be used, setting the stage for galvanic corrosion and smearing and removing Alclad.

There are strong indications that OSHA will reduce the volatile organic compound (VOC) limits for these solvents from 500 parts per million to 25-75 ppm. Such an amendment to regulations could result in the closure of most strip facilities. Chemicals also remove paints and primers from under the edges of rivet heads. It is almost impossible to blow primer and paint back into these voids. Even with electrostatic paint guns, the Faraday caging effect prevents paint from coating under rivet heads, creating an unprotected void to trap airborne chemical vapors, minute dust particles, stripping residues, and moisture. A micro battery is also formed, and galvanic and filiform corrosion can erode the fasteners and surrounding skin.

Aircraft skins heat and cool and expand and contract with altitude and weather changes. Skins are stretched, compressed, and twisted during take-off, landing, and flight maneuvers. The aircraft is designed to tolerate this action. If chemical, mechanical, and heat damage occurs to skins, the ability of the aircraft to absorb imposed loads is dramatically reduced. A crack will follow the path of least resistance, which is from rivet hole to rivet hole. In-flight air loads and cabin pressuriza-

tion can do everything else that is necessary to insure the disintegration of aircraft skins. Future and alternate methods of paint stripping should not repeat the problems caused by chemical stripping.

- **EPA Issues:** EPA requires disposal of methylene chloride stripper and the removed paint and primers that may contain eight controlled metals (arsenic, barium, cadmium, chromium, lead, mercury, selenium, silver). Methylene chloride is no longer permitted to be landfilled.
- **OSHA Issues:** It is estimated that three out of every 1,000 people exposed to methylene chloride will develop cancer. Both body and breathing protection is required, even though few strip facilities comply. The volatile organic compounds to which workers are exposed and which are released to the atmosphere are controlled.

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## Plastic Media Blasting

This method of paint removal has been used in the United States for eight years, and to date it has been a low-technology operation. These systems are very operator sensitive and require great skill. Systems that have little exacting control of plastic media flow rates, particle ejection velocity, and air pressures are in use, and have developed a reputation for severely damaging aircraft.

This lack of control over parameters with variable results has caused users to search for other methods of paint removal. Aviation-grade blasting equipment has not existed in America until recently; however, equipment and a robotic technology that allow aviation paint stripping to be accomplished with complete safety on *all* substrates have been developed in Europe.

Many users of low-technology equipment have switched to softer virgin manufactured plastic media in an attempt to reduce aircraft skin damage. The cost of this media is greater and the break-down rate is frequently high, which further increases the cost of stripping.

Aviation-grade plastic media equipment with exacting controls can use cheaper media made from hard scrap plastic. The media can be recycled, cleaned, and regraded to virgin media standards. This hard plastic breaks down slowly and strips faster; coupled with the right equipment, it is much gentler on aircraft skins than the softest of plastic media. Aviation-grade equipment

can remove all particles (no matter what the contamination rate) that have a greater density than plastic on only one pass through the cleaning equipment. The clean, graded plastic media can be reused many times. All plastic media stripping problems can be solved by using *only* aviation quality equipment.

- **EPA Issues:** EPA requires disposal of the dry paint and primers that can possibly contain eight controlled metals and are entrained in the inert plastic media. Some localities are now concerned with landfilling of the inert plastic media because of the long environmental breakdown period of these substances. Hangar exit air cleanliness is also a potential problem.
- **OSHA Issues:** OSHA requires breathing protection from the inert plastic dust and toxic paint dust, as well as personnel protection from the 15–70 psi of air pressure and ejected plastic particles. Hearing must also be protected when operating equipment.

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## Wheat Starch Blasting

This media is a biodegradable virgin (99.99 percent clean) agricultural product. Aviation-quality equipment must be used with wheat starch, just as with plastic media, for cleaning the media of dense particles. The cost per pound (\$2.25) is much higher, and paint removal rates are much slower (40 to 60 percent) than that obtained with Type II plastic media.

This process leaves an acceptable surface on most composite and metal substrates. Wheat starch is very susceptible to moisture at the 100 percent humidity level. Once wet, it is no longer effective for stripping, even if dried. Any moisture from condensation or escaping air around fittings will quickly form a large sticky ball of wheat starch that could plug a media recovery and cleaning system.

- **EPA Issues:** EPA requires disposal of the dry paint and primer particles that can possibly contain eight controlled metals. Wheat starch is rapidly biodegradable. EPA also requires hangar exit air cleanliness.
- **OSHA Issues:** OSHA requires breathing protection from the inert wheat starch dust and toxic paint dust, as well as personnel protection from the 15–60 psi blast

pressure and ejected starch particles. Hearing must also be protected during the process.

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## Sodium Bicarbonate Blasting

Sodium bicarbonate propelled under high air pressure onto painted surfaces does an effective job of removing paints and primers from thin skinned metal and composite substrates, and from heavy wall castings. High-pressure water is injected into the dispensing nozzle to control the dust problem during blasting. The clean, virgin material can be used only once. This fine powdered media is water soluble, penetrating every place that water can penetrate under pressure. When this water evaporates, the bicarbonate is left as a residue. The process requires a minimum of 10 gallons of water per square foot of surface area to wash an aircraft after stripping to remove the *surface* bicarbonate deposits; this can prevent proper fresh paint adhesion.

After the aircraft is painted and reaches elevated temperatures on the parking ramp, the entrapped bicarbonate may convert to caustic soda ash. This sodium bicarbonate media is a hydrophilic material and will absorb minute amounts of moisture from the air. Studies performed at the Brown Boveri Research Center at Baden, Switzerland, show that small amounts of moisture vapor held against aluminum alloys, high-strength aluminum, and high-strength steels can cause a rapid onset of hydrogen embrittlement and crack growth. It would be virtually impossible to mask an airplane to prevent bicarbonate media intrusion. Also, like chemical stripping, sodium bicarbonate can remove paint from under the edge rivets, increasing risk of electrolytic cell corrosion. Removal of all particles of paint smaller than the bicarbonate blast media must be performed with filtration equipment, and the wet micro-paint chips must be in accord with EPA rules on potential hazardous residues.

Bicarbonate removes paints and primers in very small particle sizes. Strontium chromate, which is used in modern day primers, is water soluble, and water is used for dust control in this process. Strontium chromate contains the heavy metal strontium, which can be absorbed by the body and stored in the bones, and does not diminish with time and age; the hexavalent form of chromate is hazardous to humans. For environmental safety, all wastewater should be free of these contaminants, and removing the chemicals from the water is difficult.

The sodium bicarbonate is more expensive to use than plastic media when coupled with aviation-grade equipment.

- **EPA Issues:** EPA requires disposal of the wet paint and primer particles that possibly can contain eight controlled metals. Control and cleaning of the water that can now contain hexavalent chrome and water-soluble strontium chromate are also required.
- **OSHA Issues:** Breathing protection from the nonharmful sodium bicarbonate and the toxic paint dust is required, as is personnel protection from the high air and water blast pressures and the noise. Personnel protection from the possibly entrained strontium chromate is also required.

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## Water Blasting

Water blasted at 20,000 to 30,000 psi is presently used to remove surface coatings. Water filtration and purification are necessary for this operation. This stripping process requires very expensive robotic control, precise angles of impingement, and exacting dwell times. Again, paint dust mixed with water results in the strontium chromate problem as previously discussed. High-pressure water intrusion through skin gaps and holes could possibly create flight safety problems. Some skin damage problems still exist with thin skins and composites.

- **EPA Issues:** EPA requires disposal of the wet paint and primer particles that can possibly contain eight controlled metals. Control and cleaning of large volumes of water that can contain hexavalent chrome and water-soluble strontium are also required.
- **OSHA Issues:** Personnel must be protected from 20-30,000 psi water blasting and high noise levels. Both hexavalent chrome and water-soluble strontium may pose a health hazard for personnel.

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## Carbon Dioxide Ice Pellet Blasting

This process is a new concept where small frozen pellets of carbon dioxide at about minus 70°C are

propelled against painted surfaces at over 200 psi. The thermal shock causes the paint and primer to quickly shrink and break the bond between the paint and aircraft skins. This carbon dioxide ice pellet process does not at present work well with thin layers of paint/primer on thin skin aluminum. The stripping of composites, especially woven fiber material and aramid fibers, has caused breakage of these fibers and matrix pullout due to rapid shrinking of the primers that are embedded around the composite filaments.

A potential problem that has not been properly investigated is the long-term effects of thermal shock on the internal aluminum grain structure. Other unanswered questions involve the effect of thermal surface shock and great temperature gradient on aviation skins, i.e., the long-term effects on fatigue life, acceleration of intergranular corrosion, stress corrosion cracking, crack propagation, and crack growth. Also, when carbon dioxide gas is mixed with water vapor a very mild carbonic acid is formed. At present, there is no data on what, if any, long-term damage may be associated with this acid formation. Further, the pellets must shatter and return to a gaseous state immediately upon impact, or skin damage can occur. High-particle velocities are achieved with over 200 psi blasting pressures.

The media is a one-time use material. The carbon dioxide equipment and the process is more expensive to purchase and operate than aviation-grade plastic media equipment to achieve the same stripping rates. At present, carbon dioxide ice blasting continues to give variable results with the same equipment.

- **EPA Issues:** EPA requires disposal of dry paint and primer particles that can possibly contain eight controlled metals. Control of fine paint and primer dust exiting the strip facility is also required.
- **OSHA Issues:** OSHA requires personnel protection from 200 psi ice particles at -70°C. Protection is also required from abnormally high gaseous carbon dioxide readings in relationship to oxygen as well as from noise and paint primer dust.

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## Flash Lamp Stripping

This method uses a high-energy light source to "vaporize" the coatings. It is a cheap method, but is very noisy and leaves a carbon deposit on substrates that must be removed with either methyl ethyl ketone (a controlled chemical) or carbon

dioxide ice pellets. The area of coverage is small and some problems have been experienced on curved surfaces and substrates of different reflectivity. The process is also very slow.

- **EPA Issues:** EPA requires containment of possible volatiles released to the atmosphere during paint vaporization, as well as disposal of burned ash that might contain eight heavy metals.
- **OSHA Issues:** Personnel must be protected from volatile exposure, high-intensity light, and excessive noise.

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## Laser Stripping

High-energy focused light can do many things, from micro surgery to manufacturing metal parts from blank castings. Lasers have many different names, such as Argon, CO<sub>2</sub>, YAG, CW, Ruby Crystal, and Excimer. Their use on aviation substrates for *effective* paint removal is in the early stages of development. Effective use of lasers will require expensive robotic controls that follow aircraft curvatures, maintain correct stand-off distances, and control speed. Slow paint removal rates and high equipment costs may be a problem, as may the difference in substrate reflectivity. There are numerous potential modes of substrate damage, such as:

- Chemical reactions
- Thermal shock
- Galvanic cell action
- Mechanical input/shock
- Anodized cracking
- Imbedded carbon
- Fiber fraying to composites
- Delamination
- **EPA Issues:** EPA requires containment of possible volatiles released to the atmosphere during paint vaporization, as well as disposal of the burned paint ash that may contain eight heavy metals.
- **OSHA Issues:** Personnel must be protected from volatile exposure, high-intensity light, and excessive noise.

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## Water Ice Blasting

Frozen water (ice), crushed and graded to very specific sizes, is now being used in an attempt to remove coatings from aviation substrates. By pumping the ice particles down the blasting tube and then injecting 70 to 140 psi of air pressure at the nozzle, the ice is propelled onto paint surfaces, whereby the impact chips or spalls the paint. To date, the process has been exceptionally slow. Very limited data are available on energy translation and Almen-strip arc-height analysis. Again, strontium chromate, which is soluble in water, can create water contamination problems and personnel hazards.

- **EPA Issues:** EPA requires disposal of *wet* paint and primer that may contain eight controlled metals. The disposal of large quantities of water possibly contaminated with hexavalent chrome and water soluble strontium is also required.
- **OSHA Issues:** Personnel must be protected from high-pressure ejected water ice (32°F) particles and excessive noise. Both the hexavalent chrome and strontium in the water residue are possible health problems.

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## Nonmethylene Chloride Stripping

Methylene chloride has produced numerous personnel and facility problems for a number of years. To reduce these hazards and problems, companies have tried to devise other methods of stripping the new two-part poly paints. Even though the new chemical stripping methods do not contain methylene chloride, they do contain numerous other chemicals, including methanol, methyl ethyl ketone, toluol, and toluene. All of these chemicals are both EPA- and OSHA-board controlled. Also, the majority of all chemical stripping agents contain substances that are presently restricted or outlawed by the Southern California Clean Air Act. More states are now following California's lead in regulating these chemicals and their emissions. The volatile fumes normally emitted from these chemicals assault the nasal passages and the eyes.

- **EPA Issues:** EPA prohibits release of the chemical emissions to the atmosphere as well as the possible eight controlled metals in the paint residue. Wash water may also contain controlled residues. Disposal of the

paint and primer with other chemical residues is required.

- **OSHA Issues:** OSHA requires personnel be protected from skin contact, breathing of volatiles, and eye damage. Kidney problems can possibly be caused by exposure to some of these chemicals, as can depletion of body fat.

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## Dissipate Chemical Embrittling Stripper

These chemicals are applied to painted surfaces to rapidly "age" the paint, resulting in numerous spider web cracks that loosen the paint and leave a dried crispy film all over the substrate. Another stripping process must then be employed to remove this layer of embrittled paint.

The process poses several problems. First, the chemicals used may be regulated, as are the volatiles that are produced. A second method of paint stripping or blasting must be employed to remove the hard, dry, cracked, and crusty paint from the substrate of the aircraft, further increasing costs.

- **EPA Issues:** EPA requires disposal of the paint and primer that possibly contain eight controlled metals. The high volatiles emitted during the dissipate embrittling process must be contained. Possible residues may be added to the paint waste, requiring safe disposal, as would possible dust released from the dry paint.
- **OSHA Issues:** OSHA requires protection of personnel from exposure to volatiles that cause eye damage and can be absorbed by the body.

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## ...But, for a Few Dollars More

Airplane supervisors and maintainers think nothing of spending large sums of money on test equipment to maintain sophisticated avionics. Special care is taken of the mighty jumbo jets that can cost between \$195 and \$205 million each. Only the best training is provided for the maintenance personnel, and automated technical data centers are installed.

But, when it comes to stripping aircraft, managers procure the cheapest equipment possible. The military normally awards contracts to

the lowest bidder, not the most technically competent. The delicacy of aviation skins, especially the new composites, is forgotten. All too often, the small amount of money allocated for a stripping facility and the associated equipment is offset by large sums of money spent each month in the procurement of the stripping agent, equipment modification, and disposal costs. By expending more money for the basic facilities and equipment, it is possible to dramatically lower the daily operational cost and waste by reducing aircraft damage, down time of aircraft and equipment, and stripping agent costs.

## Automated Plastic Media Blasting

The recommendation to use automated plastic media blasting is based on thorough investigation of every form of paint removal in the United States and Europe over the last six years. To be considered a viable process, the method had to meet three requirements. First, it had to strip an aircraft faster than any presently known method, whereby aircraft turnaround times are considerably reduced over those now experienced. Second, the process had to eliminate all EPA and OSHA concerns. This includes the stripping agent and stripping process, as well as waste streams. Third, the process had to be economical based on cost to strip per square foot of surface area. The economics of reliability and maintainability of equipment and the process are also of utmost concern and importance.

The requirements were met with plastic media blasting coupled with automated *aviation-quality equipment* and *Type II medium hardness plastic media* for both thin skin metals and composite substrates. Aluminum as thin as .012" and composites as thin as .016" have been stripped four successive times with no measurable damage, based on data from Messerschmitt, Bölkow and Blohm (MBB) of Germany.

In addition, research indicates that only robotics can effectively strip large aircraft (see Figs. 1 and 2). Two years of testing completed by Aerospatiale of France and MBB show that a roto-jet turbine attached to a robotic manipulator can strip between 861 and 1,291 square feet per hour (based on paint thickness). Plastic media is dispensed at approximately 250-285 pounds per minute from the rotating RPM controlled wheel and 90 percent of all the plastic and 99 percent of all dust and paint particles are captured at the point of stripping (see Fig. 3). With this stripping rate, a 747 can be depainted in approximately 10 clock hours with three robots and eight manually

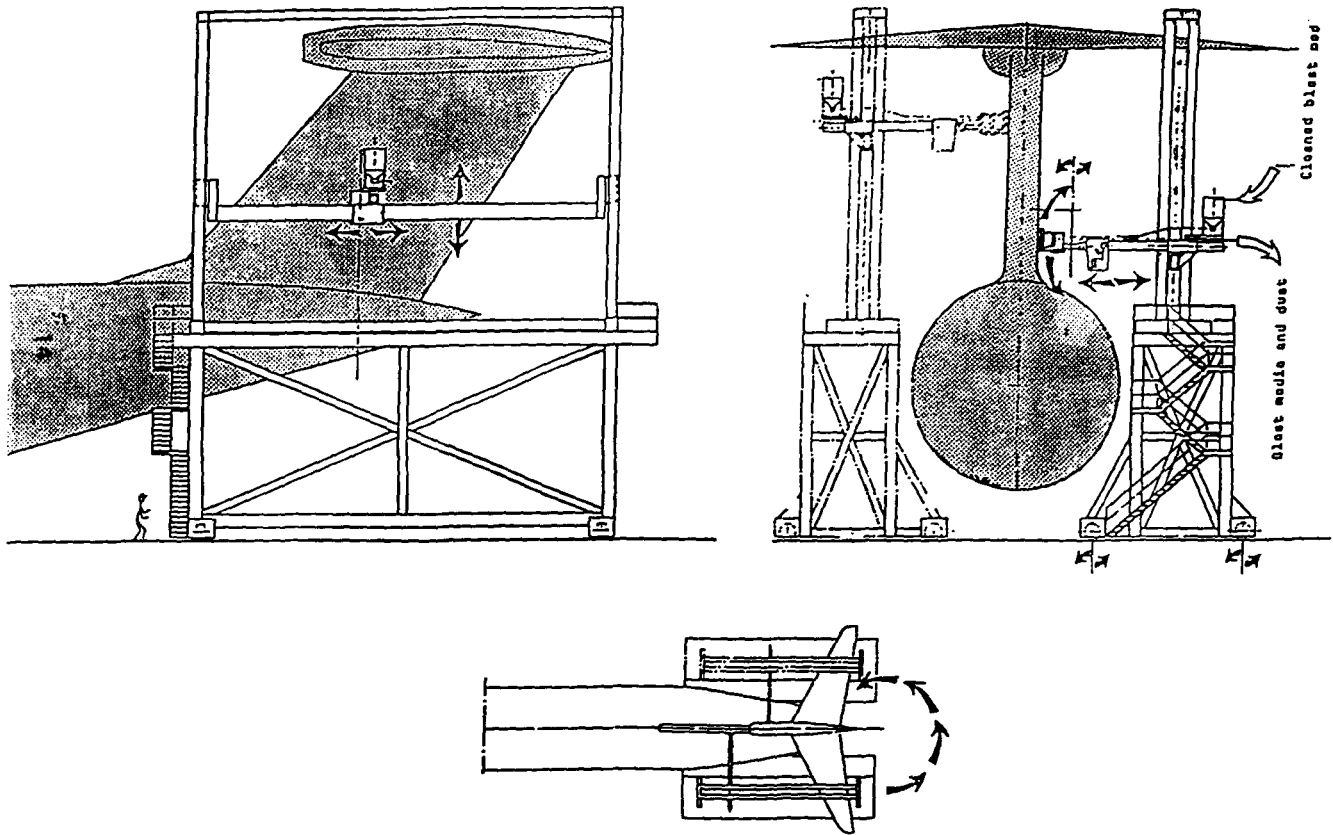


Figure 1.—Robotic manipulation stripping the aircraft, tail section.

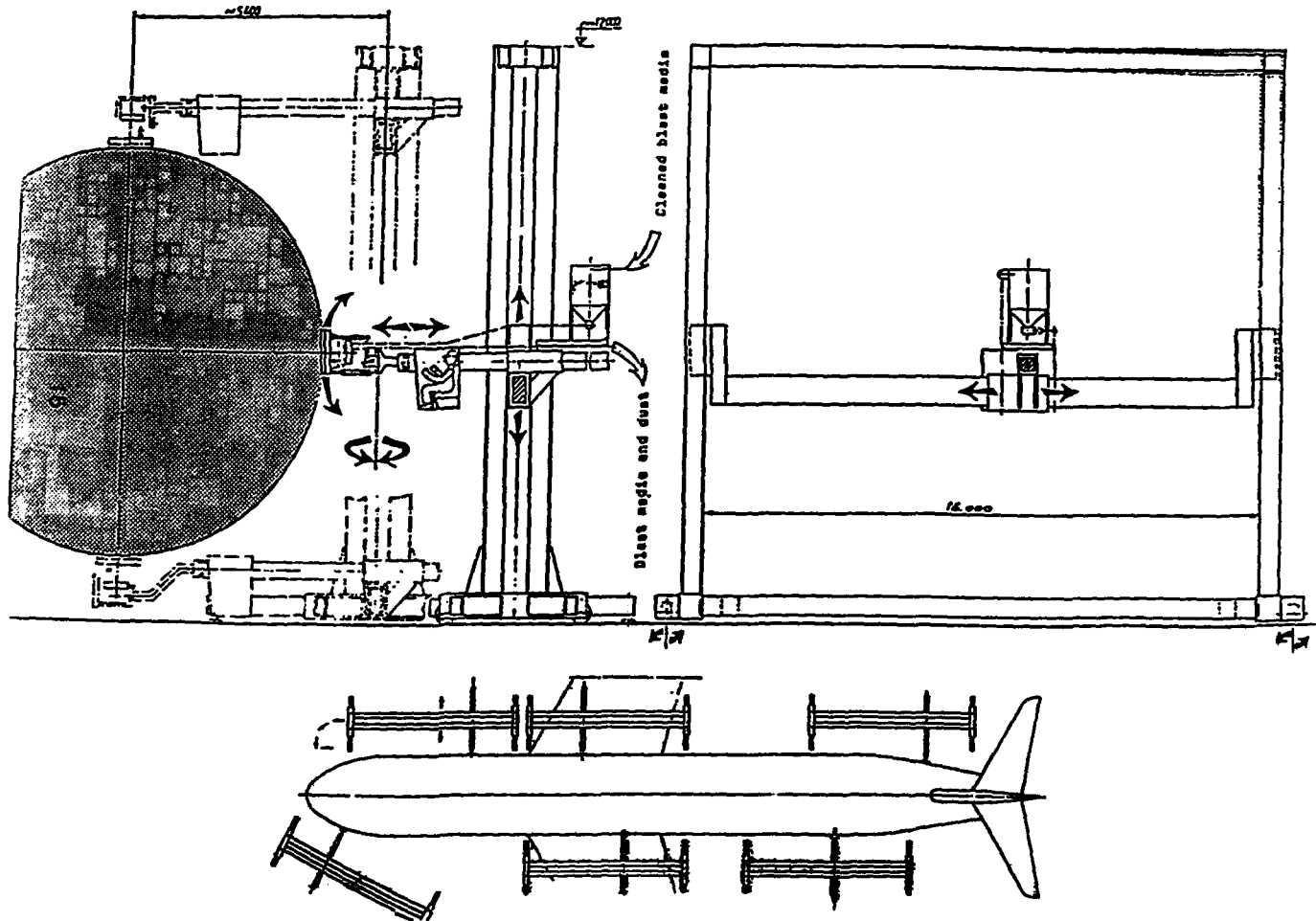


Figure 2.—Robotic manipulation stripping the aircraft, fuselage section.

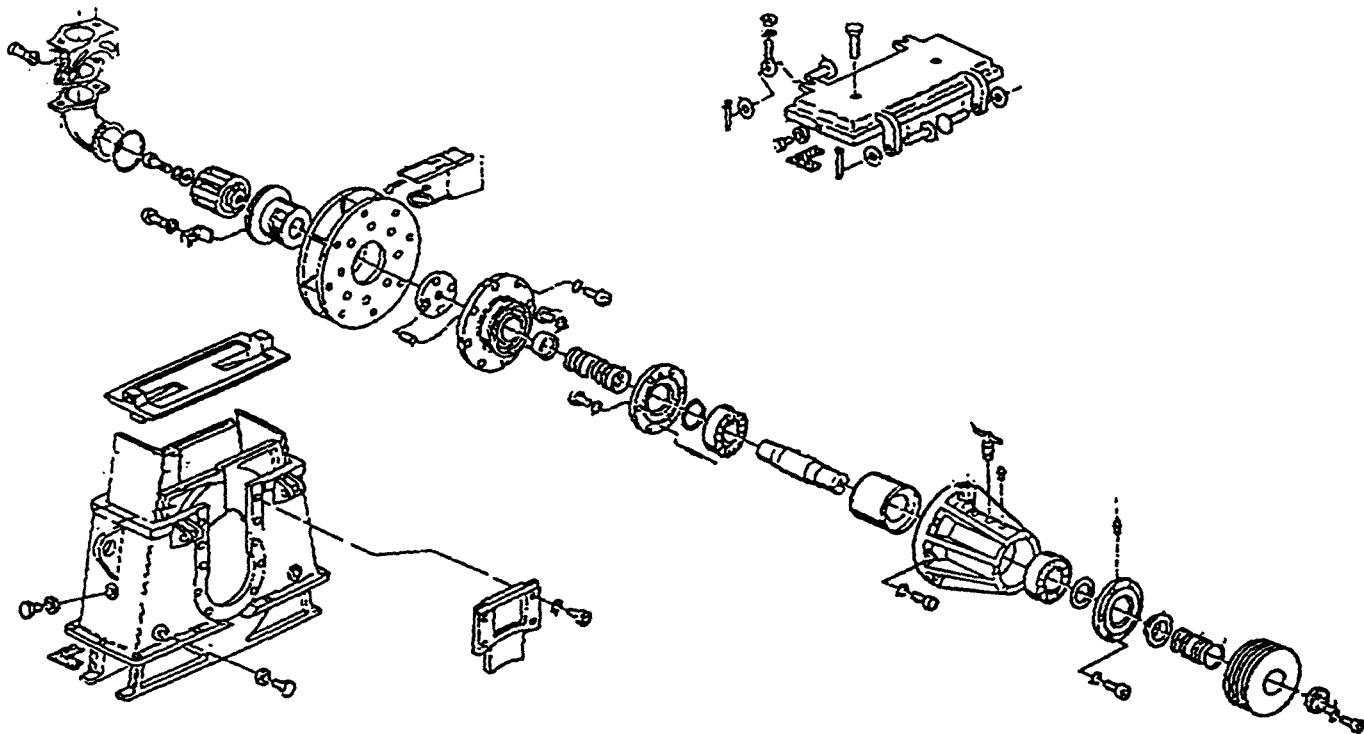


Figure 3.—Roto-jet turbine.

operated computerized hose and nozzle systems (not counting prep and deprep time). It is possible to completely strip a Boeing 747-400 in 48 clock hours, including all operations.

### **Proper Use and Equipment**

To make the equipment economical to use, it is necessary to recycle the plastic numerous times—without entraining any dust or paint particles. The equipment must also remove all ferrous and nonferrous particles over 1.5 grams/cc on one pass through the cleaning machine. This requires installation of a dense particle separator that can clean media, regardless of how contaminated, to a 99.98 percent factor verified on site by a \$40,000 photospectrometric analysis computer. All media is graded to a preselected size range to 95 percent accuracy, a higher degree than is found in the original barrels of media ordered directly from the manufacturers.

Air handling systems in both the media cleaning process and in the building are attached to reverse pulse air filters to ensure that the air exiting the building is 99.94 percent clean—in other words, cleaner than the air entering the building.

Since this equipment has the ability to separate the paint and the plastic, only the paint remains as an item of environmental safety concern. There are two methods of making this paint

nonhazardous. The first is a new totally automated system produced by Schlick Roto-Jet company of Germany that removes the eight heavy toxic metals found in paints. This is the same company that manufactures the robot, roto-jet turbine, and computerized hose and nozzle systems. The cleanliness of the moist paint residue (similar to damp sawdust) is verified on-site with a photospectrometric analysis computer. The eight heavy metals are now a minute fraction of the remaining residue. The only other industrial waste stream coming from the automated equipment is pH normalized "clean" water. The moist nontoxic paint ball can be made into decorative nonconstruction-type bricks by mixing with Portland cement or go to normal landfill.

Another method for detoxifying paint removed from aircraft has been developed by Perma-Fix, an American company. In this process, the metals within paint are first converted to a nonleachable form. For example, although lead is harmful to the body, one thinks nothing of drinking from a 34 percent Bavarian lead crystal goblet. If the goblet broke, it could be thrown into a normal landfill without creating any environmental concern. The lead is in a nonleachable and encapsulated form.

After Perma-Fix converts the metals into a nonleachable form, they encapsulate the paint. Several processes can be used, one of which is to mix the paint with Portland cement and again make decorative bricks. The material is also excel-

lent for fill underneath roadways, airport runways, and building sites. EPA-certified labs have tested this process and found no problems.

The plastic media that has been used numerous times is still clean and free of all paint or primer dust or chips. It is not necessary to dispose of this clean plastic material in controlled landfill. Type II urea formaldehyde plastic media produces the same BTU of heat as does anthracite coal when consumed in a mini blast furnace, where it produces only a very small amount of high quality black carbon soot that can be captured electrostatically in exhaust flues and given or sold to paint manufacturers. Clean, broken-down plastic media is also an excellent soil aggregate to be used in lawns and flower beds, as a filler in cement projects, or as a base for decorative non-structural bricks. It can be also sold or given to cement-curing companies to heat the large kilns.

As can be seen, these technologies are not a wish, but a reality. The equipment exists, has been tested, and all abilities to perform the stated functions have been demonstrated to the aircraft manufacturers in Europe.

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## Questions and Answers

### Description of Alternative

- **What is the product?** Plastic media blasting (using Type II urea formaldehyde, only) and Schlick Roto-Jet equipment, both turbine and computer roto-jet controlled hose and nozzle.
- **For what applications is it appropriate?** All aviation substrates, including the thinnest of metal and composite substrates.
- **How is it used?** Plastic particles (approximately 285 pounds/minute) are precisely "slung" onto the substrate from an RPM-controlled wheel. Dwell time, angle of impingement, and stand-off distance are controlled.
- **What are its potential hazards?** None.

### Performance

- **How effective is the process in stripping different coatings?** Plastic media blasting using aviation-quality equipment can precisely strip all presently known aviation coatings applied to any aviation substrate.

It cannot strip leading edge rain erosion coatings and nonskid rubberized coatings.

- **How much risk does plastic media blasting pose to the substrate?** Aerospatiale and MBB have tested the roto-jet turbine and computerized hose and nozzle (against all other forms of stripping) and found no damage to substrates.
- **How much time is required for stripping with plastic media blasting (expressed in elapsed time and labor-hours)?** Roto-jet turbine equals 861–1,291 square feet/hour using one labor hour. Computerized hose and nozzle equals 60 square feet/hour using one labor hour. Chemical stripping equals 20 square feet/hour using one labor hour.

### Waste Management

- **Is the material used recyclable?** Type II plastic media coupled with aviation-quality equipment can be recycled 8 to 10 times.
- **How much waste is generated?** What is in the waste? Two streams are generated: clean plastic media too small for reuse (3–5 percent of media used) and the paint and primer chips and dust, plus the residue dust from the air and media filter systems. By-products may be called "waste," but they can be consumed in other ways.
- **How is the waste disposed of?** The clean broken-down plastic media can be burned in a blast furnace to heat the hangar and wash rack water. The chimney carbon black can be electrostatically captured. The paint and primer can be chemically treated to convert the possible eight heavy entrained EPA-controlled metals to a nonleachable form. The resulting mass is encapsulated and made into decorative bricks, used as road bed fill, or placed in normal landfill.

### Estimated Cost of Stripping in Representative Application(s)

Cost for stripping is driven by volume of aircraft, skill in masking techniques, and costs of capital, facilities, fringe benefits, waste disposal, labor, equipment, energy, and so forth. This investigation found that few, if any, commercial air carriers or military operations know the true cost to strip aircraft. Any true and total cost between \$9–11

per square foot would actually be well within the total cost now paid for chemical stripping.

■ **What is the total cost per representative job, and cost per square foot of surface area stripped, assuming a Boeing 747-400 hangar and aircraft?**

- **Materials cost:** Plastic media consumed 50 cents per square foot for a 25,000-square-foot 747-400. Cost of media is \$1.48–\$1.60 per pound.
- **Labor cost:** \$15 per direct manhour, \$35 per company manhour.

- **Waste disposal cost:** 18–23 cents per pound of removed paint and primer to detoxify and encapsulate.
- **Equipment costs** (e.g., equipment, enclosure for blasting): \$6.8 million for robot, \$15–18 million for hangar 300' x 600' x 85'.
- **Utility costs** (e.g., water, electricity): \$1,000 per 747-400 for robotic and all other support facilities.
- **Other costs, masking materials:** \$6,000.

## Comparison of Chemical Stripping to PMB

Table 1.—Paint stripping time comparison chart for parts removed from aircraft.

	CHEMICAL STRIPPING (ACTUAL MINUTES)	PMB DRYSTRIP HOSE & NOZZLE (ACTUAL MINUTES)	ONE ROTO-JET TURBINE PMB DRYSTRIP (EST. MINUTES)
<i>DC-9 Component Parts</i>			
Flap hinge	240	5	1/3
FRWD air stair step	120	5	1/4
Oxygen bottle	120	10	1/2
Spoiler cam	60	2	1/5
Double seat frame	240	15	3
Nose wheel	60	2	1/3
<i>F-4 Component Parts</i>			
Rudder	216	16	1
INBD Le flap	168	22	1
Spoiler	40	14	3/4
OTBD Le flap	168	19	1
Aileron	388	32	2
Wingfold	525	54	2 1/2
Stabilator	589	55	2 1/2

Table 2.—Paint stripping time comparison chart for aircraft and machinery.

ITEM	CHEMICAL STRIPPING (ACTUAL MANHOURS)	PMB DRYSTRIP HOSE & NOZZLE (ACTUAL MANHOURS)	ONE ROTO-JET TURBINE PMB DRYSTRIP (EST. MANHOURS)
B-724	392	58	11 1/4
F-4 Aircraft	340	37	2 1/2
Coleman tractor	40	4	1/2
P-8 Pumpertruck	52	5	1/2
F-18 Actuator assembly	2.5	1.5	—

## APPENDIX 1

### *Additional Applications of Automated Dry Media Paint Stripping*

#### **Metal Ships/Vessels**

- **Now in use:** Europe and Asia
- **Method:** Semirobotic manipulator
- **Paint and rust removal method:** Reusable steel wire shot
- **Increased reduction:** Less manpower, energy, air pollution, legal and medical problems, OSHA and EPA problems, toxic waste. Manipulator washes, scrubs, paint strips; removes corrosion, prepares for primer and paint.

#### **Economics**

Faster water wash and brush scrubbing with high-pressure water blasts.

- Sides washed at 492–1,968 sq. ft./hour.
- Bottom washed at 1,453 sq. ft./hour.
- Sides scrubbed at 2,090 sq. ft./hour.
- Bottom scrubbed at 2,096 sq. ft./hour.

Ship can be stripped of paint and rust.

- Reusable hard spring steel wire shot is thrown onto the surface with a controlled speed turbine wheel (centrifugal dispensing system).
- Wire shot ricochets off surface and removes paint, primer, and rust. All material is captured at the point of surface impact and recirculated.

#### **Environmental**

The paints and primers that are separated from the wire shot can be chemically treated to convert the eight EPA-controlled metals to a nonleachable form. This residue is thus encapsulated and can now be used for soil stabilization, road foundation, aviation runway fill, filler in decorative nonconstruction brick, or filler in blacktop paving. A computer-operated automatic system also can be purchased to reduce the paint/primer into a recyclable form.

#### **System Engineering**

Adaptable to any dry dock area and suitable for the largest ocean vessels.

#### **Cargo Containers**

- **Now in use:** Asia and South America

- **Method:** Semiautomatic manipulator

- **Paint and rust removal method:** Steel slag

- **Increased reduction:** Containers are loaded onto a conveyor and are stripped inside and outside at the same time with roto-jet centrifugal wheel turbines. A visual inspection allows rapid repair of any previous damage. Automated system can prime and paint to the desired color.

#### **Economics**

Fast, efficient, automatic, reusable stripping media separates paint and primer from the stripping media; few people needed.

#### **Environmental**

See ship stripping.

#### **System Engineering**

Can be designed and built to suit the size of any operation.

#### **Ground Transportation Vehicles**

- **Now in use:** Europe, Asia, Middle East, Australia, United States, South America, Africa, and Canada.

- **Method:** Steel shot, steel slag, plastic media, garnet stone, wheat starch, coal slag.

Steel trains with rust are best cleaned with an abrasive material. Totally automated systems can be put together.

Stainless steel, thin sheet steel, fiberglass, and aluminum vehicles are best stripped with plastic media. A good cleaning system to allow media to be reused numerous times and effectively remove dust, paint, sand, and trash is essential.

Automated systems and manual systems can be used together to most effectively meet the need of a customer and all EPA and OSHA requirements.

#### **Economics**

Fast, efficient, safe, reusable media; removes paint/primer from the media.

#### **Environmental**

See ship stripping.

### **System Engineering**

System can be designed for specific needs for rail cars, tractor trailers, Army tanks, cannons, radar dishes, corvettes, and subway carriage cars.

### **Large Pipes**

A custom-designed system for stripping, derusting, non-destructive inspection, and coating application for the inside and outside of large pipes can be built. Present applications clean torpedo and missile tubes of hard deposits. Other systems can strip large water or chemical pipes. Even delicate stripping of the air intake tunnel of the F-16 fighter is being accomplished.

### **Economics**

Now that sand blasting is being curtailed in many states, a fast, efficient system using reusable media that separates the contaminants from the media is important. The use of an automatic system is safe, fast, and very efficient with removal rates well above what can be accomplished by workers.

### **Bridges**

New systems are presently being developed in Europe to strip steel bridges with a reusable media that captures the paint, primer, and media at the point of impact. With sand blasting rapidly becoming an uneconomical method to strip large bridges due to the EPA, OSHA, and

"capture" rulings, other methods must be found. The cost to strip, derust, and treat bridges has climbed steadily from \$8 to \$10 per square foot to \$24 per square foot. Whether the bridge has steel girders, cables, open frame, or tube construction, an economical system can be developed.

For waste handling, see ship stripping.

### **Lead-based House Paint**

One of the major challenges facing the housing industry and the government today is what to do with the 78 million homes that are covered with numerous layers of peeling lead-based paint. Automated technology exists to rapidly strip wood, cinder block, brick, and stucco homes. This is not a dream but a reality of engineering and technology.

The average 2,000-square-foot floor-space house will average 1,800 to 2,700 square feet of exterior surface. Equipment exists to strip these surfaces at 300 to 1,000 square feet per hour. All necessary items are contained in three 40-foot tractor trucks. This includes the manipulator stripping equipment, the reclaim system, the paint and stripping media separator system, the environmental air wall system to protect the community, all plastic canopies, lighting systems, air compressors, and electrical generators.

EPA detoxifying and disposal requirements would have to be met. Mobile, fully automated equipment exists that would make the lead paint nonhazardous and yield the lead as a resalable, recyclable item.

# Perspectives on Surface Preparation with CO<sub>2</sub> Blasting

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**U**ntil recently, CO<sub>2</sub> blasting has been used primarily as an industrial cleaning technology to remove manufacturing process residues. Common applications include cleaning molds, ovens, conveyors, extruders, and presses. However, there has been increasing interest in using CO<sub>2</sub> blasting for paint stripping and surface preparation because the cleaning agent, small pellets of dry ice, immediately disappears upon impact and returns to its natural state in the atmosphere.

The performance of CO<sub>2</sub> blasting has been overstated in both positive and negative terms for a variety of reasons. The net result has been confusion among end users. Dry ice blasting is not a panacea that will solve all your surface preparations needs, but what it does well, it does better than any other technology available.

The concept of using dry ice pellets to clean surfaces is relatively new. In 1977, Lockheed Corporation filed a patent on a single hose system that used a supersonic venturi. The system configuration was later improved to a two-hose system, which was the basis for the second Lockheed patent.

Dry ice blasting was not available as an off-the-shelf product until 1986. Two companies in the United States manufacture CO<sub>2</sub> blasting equipment, one of which is Alpheus. We purchased the exclusive rights to the technology from Lockheed. A third company is located in Europe.

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## Dry Ice Blasting Process

Although each uses dry ice as the cleaning media, these companies have distinctly different ideas about surface cleaning and have designed their systems to reinforce these concepts. Because of these engineering differences, it is not possible to generalize one system's approach with the other two.

The core system is connected to both an air compressor and a liquid CO<sub>2</sub> storage vessel. Liquid CO<sub>2</sub> is used to make snow, which is then extruded into pellets of a predetermined size from 1/4 inch down to snow. The pellets are fed through an airlock out to the nozzle, where they are accelerated toward the object to be cleaned.

To evaluate the advantages and limitations of CO<sub>2</sub> blasting, it is necessary to understand the mechanics of surface cleaning with dry ice pellets. Visually, CO<sub>2</sub> blasting appears similar to the traditional process with grit. However, the actual cleaning dynamics differ significantly. Grit works through a chiselling action that not only slashes or cuts the coating but also the underlying surface. In contrast, CO<sub>2</sub> blasting can best be described as an impact-flushing process. As it impacts, the pellet causes surface and subsurface fractures in the coating. The pellet breaks apart and creates a high-velocity flow of dry ice particles that mushroom out from the point of impact, creating a lifting and shearing effect. When viewed with high speed

film, the paint seems to be lifted from the inside out.

Intuitively, the idea of helping the cleaning process with a large thermal drop is both logical and appealing. However, the belief that cold weakens the coating system through embrittlement and/or the differential contraction between the coating and substrate just is not true in most cases.

With the Alpheus system, it is possible to adjust the temperature of blast air between -100° and +100°F. Our testing has shown that, with the exception of some paraffins, release agents, and sealants, there is no benefit from cooling the surface. In fact, with some coatings (such as coal tar epoxy), supercooling the surface drops the cleaning speed to less than one-fifth of that attainable at ambient or heated temperatures.

Another consideration is the excellent solvent characteristics of liquid CO<sub>2</sub>. It has been hypothesized that—at the moment of impact—a thin layer of liquid CO<sub>2</sub> instantaneously appears and then disappears and that this assists the cleaning process.

CO<sub>2</sub> is a natural component of our atmosphere. Blasting with dry ice pellets does not create any additional CO<sub>2</sub>. It only uses what is already there and thus does not contribute to the Greenhouse Effect. The equipment is reliable, easy to use, and requires only a half-day of operator training. Alpheus has units in robotic applications running 22 hours a day, seven days a week.

CO<sub>2</sub> is heavier than air and as such displaces oxygen. In most workplaces, the amount of CO<sub>2</sub> coming from the nozzle is not a problem; it is easily handled by the facility's ventilation system. In closed areas such as storage tanks, operators should use ventilation and respirators. Inexpensive CO<sub>2</sub> monitors can be installed to automatically shut down equipment if the levels of concentration exceed Occupational Safety and Health Administration standards.

## Advantages

Since there is no incremental waste from the pellets, cleanup is confined to the residue removed. There is no danger of grit entrapment or sedimentation, which reduces or even eliminates the need to mask or disassemble the area being cleaned. The process will not affect water usage restrictions and has been safely used to clean live electrical subsystems. The pellets will not change the surfaces of precision-machined parts. By varying the blasting parameters, we have successfully cleaned everything from circuit boards to I beams.

## Limitations

Dry ice pellets disintegrate upon impact and therefore do not ricochet off the target surface to clean hidden backsides in complex structures. Cleaning performance is generally best when the angle of impingement is between 75 to 90 degrees to the working surface; more glancing blows are ineffective for paint stripping. Lastly, CO<sub>2</sub> blasting cleans down to the original surface geometry. If a new anchor pattern is needed, another method must be used.

Although removal rates can equal traditional grit blasting in some applications, dry ice blasting is often much slower. Noise levels generated when operating blasting equipment at high pressure (>150 psi) range from 105 to 120 dbA, depending on the working environment.

Basic systems start at \$100,000.

## Good Applications

Surface preparation is rarely limited to the act of cleaning. As the time and cost of the pre- and post-cleaning activities increase for any given application, so does the attractiveness of CO<sub>2</sub> blasting. Two other favorable application conditions where CO<sub>2</sub> excels are when (1) the surface must not be damaged or altered, or (2) a company requires an exceptionally clean, residue-free surface.

A few examples of good applications are given in the following paragraphs.

- **Nuclear test cells:** Radioactive epoxy paint was removed from high density concrete in nuclear test cells. This two-week job resulted in disposal savings of \$500,000.
- **Water storage tanks:** A company wanted to replace a coal tar epoxy coating in a potable water storage tank. Power tools removed most of the coating but were unable to clean the seams, which was done quickly by CO<sub>2</sub> blasting.
- **Food processing areas:** A cracker plant wanted a multi-layered, industrial alkyd coating removed. Grit blasting or solvents could be used in the food production areas, and the plant's wood floors eliminated use of water blasting. CO<sub>2</sub> blasting cleanly eliminated the coating.
- **Chemical refineries:** Pressure vessels at a chemical refinery must have the coating over welds periodically stripped to permit

inspection for fatigue cracking. Grit blasting will fold the metal over any cracks, making suspect the results of a dye penetrant inspection. CO<sub>2</sub> will clean and strip without hiding the cracks and can also remove the dye penetrant after the inspection is completed.

- **Metal plating facilities:** Corrosive deposits form on equipment, walls, and ceilings at a metal plating plant. Grit can become contaminated, creating a disposal problem, and water would activate the chemical nature of the deposits. CO<sub>2</sub> blasting successfully removed deposits and old paint, thus providing a residue-free surface for repainting.

## Steel Structures Painting Council Standards

Dry ice blasting meets or exceeds the following SSPC standards.

- SP-1 (Solvent cleaning)\*
- SP-2 (Hand tool cleaning)
- SP-3 (Power tool cleaning)
- SP-6 (Commercial blast)\*
- SP-7 (Brush-off blast)

SP-1 and SP-6 have asterisks, which I will explain.

- **SP-1:** Dry ice blasting does an excellent job of removing oil, grease, and dirt. Alpheus has a unit in the Space Shuttle Program that high-performance cleans oils and particulates down to the microcontaminant level, even to the point of removing fingerprints. However, all cleaning is simply the relocation of dirt from an unacceptable location to another one that is more acceptable. With complex structures, such as printing presses, care must be taken not to relocate the dirt to a previously cleaned area. Operator skill comes into play here.
- **SP-6:** CO<sub>2</sub> blast cleaning meets the SP-6 standard when there is no heavy corrosion and the existing anchor pattern under the old coating is acceptable. CO<sub>2</sub> blasting cannot meet this standard with new steel because it will not remove mill scale.

## Cleaning Results

Now, how fast does CO<sub>2</sub> blasting clean? Surface preparation experts would say that the outcome depends on such things as the coating's thickness, age, original anchor pattern, and structure complexity—and they would be right. Nevertheless, laboratory test specimens can be a good starting point for discussion.

KTA-Tator prepared multiple test panels of eight different paint systems. Each panel was grit-blasted to an SP-10 near-white finish with a nominal anchor pattern of 2 mils. Paint was applied and cured according to the manufacturer's specifications. A Taguchi test structure was established to optimize the blasting parameters for each paint system using nine variables, including pellet size, velocity, quantity, and temperature. The panels were cleaned with CO<sub>2</sub> blast equipment until all paint had been removed and the original SP-10 standard was again achieved. The results are shown in Table 1.

Table 1.—Cleaning results for test specimens.

200 FT <sup>2</sup> /HR	40-80 FT <sup>2</sup> /HR	20 FT <sup>2</sup> /HR
• Inorganic zinc	• Acrylic latex	• Coal tar epoxy (2 coats)
• Vinyl (2 coats)	• Industrial alkyd (2 coats)	• Polyamide epoxy (2 coats)
	• Baked enamel	• Epoxy mastic polyurethane

Some of the information presented in Table 1 requires further explanation. Let's start with the inorganic zinc. The removal rate was higher than we expected. We checked the curing of the sample and found it was in accordance with the manufacturer's guidelines. We are now awaiting receipt of additional panels to replicate the test.

The test removal rates for the latex, alkyd, and coal tar epoxy were all much slower than those in Alpheus' field experience. For coal tar epoxy and industrial alkyd, we attribute this to the fact that, as paint ages, it loses adhesion and thus CO<sub>2</sub> pellets remove it more easily. Also, we have had removal rates in excess of 300 square feet per hour for latex paint. We plan to explore the reasons for the slower removal rate in the test.

The two epoxy systems really are that slow. For these coating systems, we are testing CO<sub>2</sub> used in tandem with other technologies. Maxwell Laboratories and Polygon Industries are working with Alpheus to explore CO<sub>2</sub> blasting with their flashblasting technology for paint removal. Laboratory removal rates of 800 square feet an hour have been achieved. Alpheus has also worked with various chemical companies on pretreat-

ments. These are sprayed on the painted surface, weakening the adhesive bonds chemically. Then the paint is removed quickly with CO<sub>2</sub> blasting.

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## Conclusion

Alpheus has committed significant resources to furthering the science of CO<sub>2</sub> blasting. At our test center, a number of projects are being conducted, including:

- Quantification of pellet flow upon exiting from the nozzle,
- Effects of supercooled, ambient-heated drive air, and
- Effects of pellet impact energy on coatings and substrates.

Many of the results will be published to help the industrial community better understand and use the unique characteristics of CO<sub>2</sub> blast cleaning.

# Water as a Tool: Alternative Methods of Reducing the Environmental and Human Health Risks in Paint Stripping

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## Introduction

"Water as a tool" is used in many markets and applications, not only as a paint stripping medium, but also in cleaning other environmental and safety conscious applications. Since there are numerous applications, we have chosen the paint stripping of aircraft for today's presentation.

### *Typical Applications in Markets for Pressurized Water as a Tool*

The following industries typically use pressurized water as a tool:

- Agriculture
- Airline
- Automotive
- Beverage
- Building and Concrete
- Cellulose and Paper
- Cement
- Chemical
- Energy
- Engineering
- Food
- Glass, Porcelain, and Ceramic
- Iron, Steel, and Metal

- Military Fields
- Mining
- Municipal Services
- Painting
- Plastics Manufacturing
- Public Transport
- Railroads
- Shipbuilding
- Wood

Pressurized water can be used to reduce the risk to man and the environment in aircraft paint stripping applications. Lufthansa Airlines has made a substantial investment in a procedure the Germans call aqua stripping. This approach utilizes pressurized water up to 500 bar/7,250 pounds per square inch for the safe and environmentally sound removal of paint from aircraft. Lufthansa estimates that this new procedure could save them initially DM 10 million per year, as compared to the previous methods utilizing caustic chemicals.

Aircraft have to be completely overhauled every five to eight years. Each "D-check," as it is called, lasts a good four weeks and usually takes 30,000 manhours to complete. An important part of such an overhaul involves renewing the paint job. After thousands of flight hours, even the best paint is dull, brittle, and cracked. Before, a strong corrosive agent containing phenol methylene chloride and other substances was applied, which

caused the paint to swell and loosen its hold on the surface. The paint was then scraped off by hand. This process was repeated until the surface was cleaned.

This procedure has several drawbacks. Phenol is toxic and highly caustic. Safety regulations require workers to wear protective clothing and gas masks (both of which have to be thrown away after a single use). These two materials cost Lufthansa approximately DM 1 million per year. Protective coverings on the aircraft and surrounding areas also have to be used and discarded. The residues, clothing, and coverings have to be disposed of as toxic waste at great expense. Several tons of waste material accumulate from stripping the paint off a single aircraft. The waste material is typically disposed of by incineration, which pollutes the environment.

Methylene chloride, highly volatile and known to cause cancer, is hardly a less critical substance than phenol. Like all other chlorinated hydrocarbons, it damages the earth's ozone layer. Milder corrosives are not capable of removing the type of airplane paint currently in use. Aircraft paint must meet very high durability standards, withstand scorching heat, and yet be crack-resistant at such low temperatures as 60°C. Year after year it must stand up to an intense ultraviolet radiation at altitudes of 10,000 meters.

How can airplane paint which is invulnerable to such extreme conditions be removed without inflicting damage on the environment? Chemicals are not the answer.

Water as a tool, however, is a perfect solution as recently demonstrated at the Lufthansa hangar in Hamburg. After three years of testing, conducted in conjunction with WOMA Corporation using pressurized water up to 500 bar/7,250 psi, computer evaluation of the test data results revealed certain regularities. If you determine the type, thickness, and age of the paint used, you can use a formula developed to calculate the appropriate pressure and temperature. The appropriate pump and tools used to apply water at the appropriate pressure and temperature will strip off a layer of paint only one-tenth of a millimeter thick without damaging the aircraft. Sometimes a chemical swelling agent is applied to thicken the paint coat to make it more vulnerable to the pressurized water spray. Benzyl alcohol is a perfect swelling agent. It is biodegradable and completely nonpoisonous. The time required for the agent to achieve the desired effect is calculated precisely. If the softening agent is left on for a longer period, pressurized water spray also will remove the primer coat.

In testing this application it had to be proven that the vibrations and pressures created by the pressurized jet of water spray did not subject the airplane's thin aluminum skin to undue stress or damage. A series of tests were carried out by independent institutions under the supervision of Boeing Aircraft Company. The vibrations and stresses were measured with lasers and a variety of other testing equipment, and these values were compared to those resulting from the mechanical stress of orbital sanders and polishing machines. All misgivings were dispelled, and in late 1989, Boeing gave the go-ahead for the procedure using pressurized water in paint stripping.

Boeing is looking for an alternative to harsh chemical paint stripping in Seattle, Washington. However, they are placing their hopes on a kind of shock therapy that calls for spraying aircraft with a barrage of dry ice crystals. Cold shock causes the paint to peel off and drop to the floor with crystals of dry ice. The crystals of frozen carbon dioxide (extracted from the air) vaporize completely, leaving behind only the paint particles on the floor. That, at least, is how it works in theory. This technique was once a favorite of some of Lufthansa's engineering staff. But like so many other approaches, this one is plagued by nasty drawbacks. The refrigeration machine and dry ice blower are voracious consumers of energy. Personnel have to wear heavy protective clothing similar to that used in sandblasting. Not least of all, the cleaning area must be equipped with an elaborate ventilation system to prevent workers from being knocked unconscious by carbon dioxide vapors. Furthermore, it has been observed that the heavy artillery of ice crystals dents the thin aluminum sheets, leaving the planes' outer skin wavy.

The same problem occurs when the plane is sprayed with granulated plastic. Boeing has approved this technique of paint removal on its aircraft, but only one such treatment is allowed per plane. Stringent safety precautions must be taken, since the fine dust cloud of plastic and paint particles can combine with air to form an explosive mixture.

Paint stripping with laser beams is still at the laboratory stage. In this application, the laser would heat the paint to a point of vaporization. Many are critical of this approach since problems such as filtration of the resulting gas have not been thought out.

Water as a tool in paint stripping has none of these disadvantages. At the beginning of the decade, water as a tool was successfully used, and each day we learn a little bit more. This technique is not only ecologically safer than chemical paint

removal, but it typically costs less and takes less time.

A new paint stripping facility is being built by Lufthansa on the edge of the Hamburg airport complex. When it begins operation in 1992, the era of chemical paint removal for Lufthansa will have drawn to a close. In this new facility, large remote control units located on platforms and equipped with six rotating jets will take on the task of stripping paint from the entire aircraft. In a single work cycle, they will lay bare a swath nearly one meter wide. It is anticipated that only a few isolated spots on the airplane will require manual water stripping. A processing facility will filter the paint particles out of the circulating water, reducing the amount of hazardous material to be disposed of and allowing the water to be reused.

The total investment with this new technology will have paid for itself in a year's time. But more important than earnings and the competitive edge gained by Lufthansa, since aircraft planes from

throughout the world are overhauled in Hamburg, is the growing sensitivity to environmental problems. Water as a tool addresses problems by offering an ideal mix of economy and ecology.

Before you launch any project utilizing pressurized water as a tool, be sure to seek a professional in the field. I'm sure you will find them helpful—some companies have more than 30 years of experience. There are variables such as pressure, flow rate, standoff, speed, and determining what power source or tools are required, that have to be considered to accomplish the task. In many years of experience in this field, I have seen many people waste a lot of time and money misapplying water as a tool. If you take advantage of the resources available to you, I am confident you will find pressurized water can solve many problems, save money, and be a friend to the environment as well. Paint removal is just one of many applications for which you may choose to use water as a tool.

# CO<sub>2</sub> Pellet Blasting for Paint Stripping and Coatings Removal

**Wayne N. Schmitz**

*McDonnell Aircraft Company*

*St. Louis, Missouri*

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## Introduction

A major element of every McDonnell Aircraft Company (McAir) program is integrated logistic support of the fielded weapon system. As more aircraft are manufactured with composite materials to reduce weight while maintaining high strength structures, the requirement to completely remove such things as paint, primer, and rain erosion coatings to make bonded repairs becomes critical.

While composite structures are not subject to corrosion or fatigue cracking, the remaining metal portions of the airframe must be inspected periodically to preclude catastrophic failures from metal fatigue. Again, surface coatings must be completely removed to inspect these areas.

Paint stripping materials that use phenol-based methylene chloride chemicals are not acceptable because composite materials are susceptible to damage, and maintenance personnel injuries and toxic wastes result from the use of these hazardous materials. Therefore, McAir began a search for new paint stripping technologies to satisfy integrated logistic support requirements.

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## The Search

McAir's search for a new process to strip paint, primer, and a variety of surface coatings was conducted under the following constraints:

- The process must not compromise the structural integrity of the aircraft. This requirement is far more stringent than merely not damaging the surface of the substrate as it includes substructure.

- Toxic waste and the use of hazardous materials must be eliminated.
- Disposable materials (removed paint, etc.) plus any worn-out, contaminated media must be reduced by 90 percent.
- The process must reduce maintenance manhours, overall stripping costs, and aircraft cycle time by 50 percent.

The technologies McAir investigated fell into three categories:

### ■ Dry Media Blasting

- Carbon dioxide (CO<sub>2</sub>) pellets
- Plastic grit
- Wheat starch
- Walnut shells (and the like)

### ■ Liquid Media Blasting

- Medium pressure (7000 psi) water jet
- High pressure (32,000 psi) water jet
- Water ice slurry
- Sodium bicarbonate slurry

### ■ Pulse Light Energy

- Lasers
- Xenon flashlamps

Each of these technologies exhibited one or more of the following problems:

- Potential damage to substrates and/or substructure (as a secondary effect),
- Media intrusion and airframe contamination,

- Damage to polysulfide sealant and rubber seals,
- Corrosion,
- Aircraft pre-cleaning and post-stripping cleanup requirements,
- Hazardous environment for operators,
- Need for special facilities, toxic waste capture system, media-removed coatings separation and recycling system, and
- Spent media and toxic waste disposal costs.

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## The McAir Choice

A comparative study of these technologies was conducted to determine which process could effectively strip military specification paint and primer within the specified constraints. Two additional categories were added to those identified problems to arrive at bottom line effectiveness for each process: the life cycle cost benefits for a total weapon system and the aircraft thru-put rate.

McAir chose CO<sub>2</sub> pellet blasting as the technology offering the greatest benefits both in terms of maintenance cost reduction and compliance with environmental issues. Because the pellets are made from liquified CO<sub>2</sub> gas (a natural atmospheric element) and sublimate instantly on contact back to that gas, they represent an environmentally safe process for the operator.

Since there is no media to dispose of, only paint chips remain. Their volume compared to toxic waste generated by chemical stripping processes represents a 96 percent reduction. In addition, CO<sub>2</sub> pellet blasting is generally benign to most substrates. Since there is no solid media, intrusion is not a factor, which eliminates the vast percentage of aircraft masking as well as post-stripping cleanup, media disposal costs, and the requirement for a media separation and recycling system. Elimination of these tasks reduces maintenance manhours by at least 50 percent.

Another benefit of CO<sub>2</sub> pellet blasting is its ability to remove a broad range of aircraft surface

coatings, sealants, and adhesives. Best of all, there is no need to pre-clean the aircraft; the process instantly removes such materials as grease and oil while stripping paint. The economic bottom line is an overall stripping cost of \$5 a square foot compared to \$19-plus a square foot for current chemical processes.

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## Concerns about CO<sub>2</sub> Pellet Blasting

Every paint stripping technology McAir investigated exhibited negative characteristics to a greater or lesser extent, and none of the processes has been thoroughly tested with respect to all potential effects on aircraft structures. For all of its excellent benefits, CO<sub>2</sub> pellet blasting still requires further testing for fatigue life degradation, crack growth potential, and the possibility of inducing micro-cracking in composite materials.

Some of the effects of CO<sub>2</sub> pellet blasting are visual. At the blast pressures required to effectively remove paint and primer, soft aluminum skins less than 0.032 inch thick show evidence of peening. Thermoset composite materials are easily damaged unless very close attention is paid to dwell time and stand-off distance. One other aspect of CO<sub>2</sub> pellet blasting is a relatively slow stripping rate (0.5 square feet per minute) on alclad-coated aluminum skins and thermoset composites. Clearly, further optimization of the process is required before CO<sub>2</sub> pellet blasting can be used to remove paint and primer from a wide range of aircraft substrates.

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## Conclusion

Because CO<sub>2</sub> pellet blasting offers outstanding environmental gains, McAir will continue research on its performance. Preliminary results of combining CO<sub>2</sub> pellet blasting with other paint stripping technologies look promising, proving once again that there are no simple solutions and no one process is a panacea for all problems.

# Pulsed Light Flashlamp System for Paint Removal in Maintenance Stripping

**Anthony P. Trippe**

*Maxwell Laboratories  
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**M**axwell Laboratories' paint stripping technique uses intense pulses of light to vaporize the paint, a microlayer at a time. The repetition rate of the flashlamp, the intensity level of the light pulsed from the lamp, the pulse duration (or pulse width), and the spectral content of the lamp's light output all contribute to the rate of paint removal. Typical physical parameters of the Flashblast technique are shown in Table 1.

**Table 1.—Typical Flashblast specifications.**

Optical energy density	– 1 TO 20 J/cm <sup>2</sup>
Area covered	– 20 TO 300 cm <sup>2</sup>
Pulse repetition rate	– 0.1 TO 5 Hz
Pulse width	– 0.5 TO 2 ms
Power efficiency	– 30 percent

A typical Flashblast system is illustrated in Figure 1. One of the major components, the cleaning head, contains the flashlamp, a reflector, a vacuum system to remove vaporized gases and residue particles, and a flow of cooling water for the flashlamp. The pulsed power source and power cable are other major components.

Some of the Flashblast system's main coatings removal and treatment applications are:

- Curing resins and inks
- Synthesizing chemicals
- Purifying silane
- Annealing semiconductors
- Preparing surfaces on reinforced plastics
- Stripping paint from aircraft
- Maintaining ship surfaces

- Demilitarizing chemical warfare agents
- Decontaminating surfaces exposed to chemical warfare agents
- Removing protective oil films from new sheet steel
- Detoxifying synthetic gas
- Treating industrial wastes

Currently, Maxwell Laboratories is developing commercial equipment that can depaint military and commercial aircraft. Figure 2 shows a block diagram of an industrial Flashblast system that can remove paint from airplanes.

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## The Hybrid Technique

A hybrid approach to flashlamp depainting is being developed by Maxwell Laboratories and a team of other companies. This technique encompasses a system with a robotic crane that carries a flashlamp head and CO<sub>2</sub> pellet blast spray head, along with sensors on its arm. The flashlamp process removes the paint and the CO<sub>2</sub> pellet wash completes the final surface cleaning.

A nozzle that accelerates solid CO<sub>2</sub> pellets at low velocity with a stream of compressed air is built into the cleaning head behind the flashlamp. When the pellets hit the surface, a kinetic cleaning action results from the mass impact, along with a scrubbing action from sublimation of the CO<sub>2</sub> as it goes from a solid to a gaseous state. Residual paint in cracks and crevices, along with ash remaining after Flashblast treatment, is effectively removed by the CO<sub>2</sub> follow-up wash and flushed

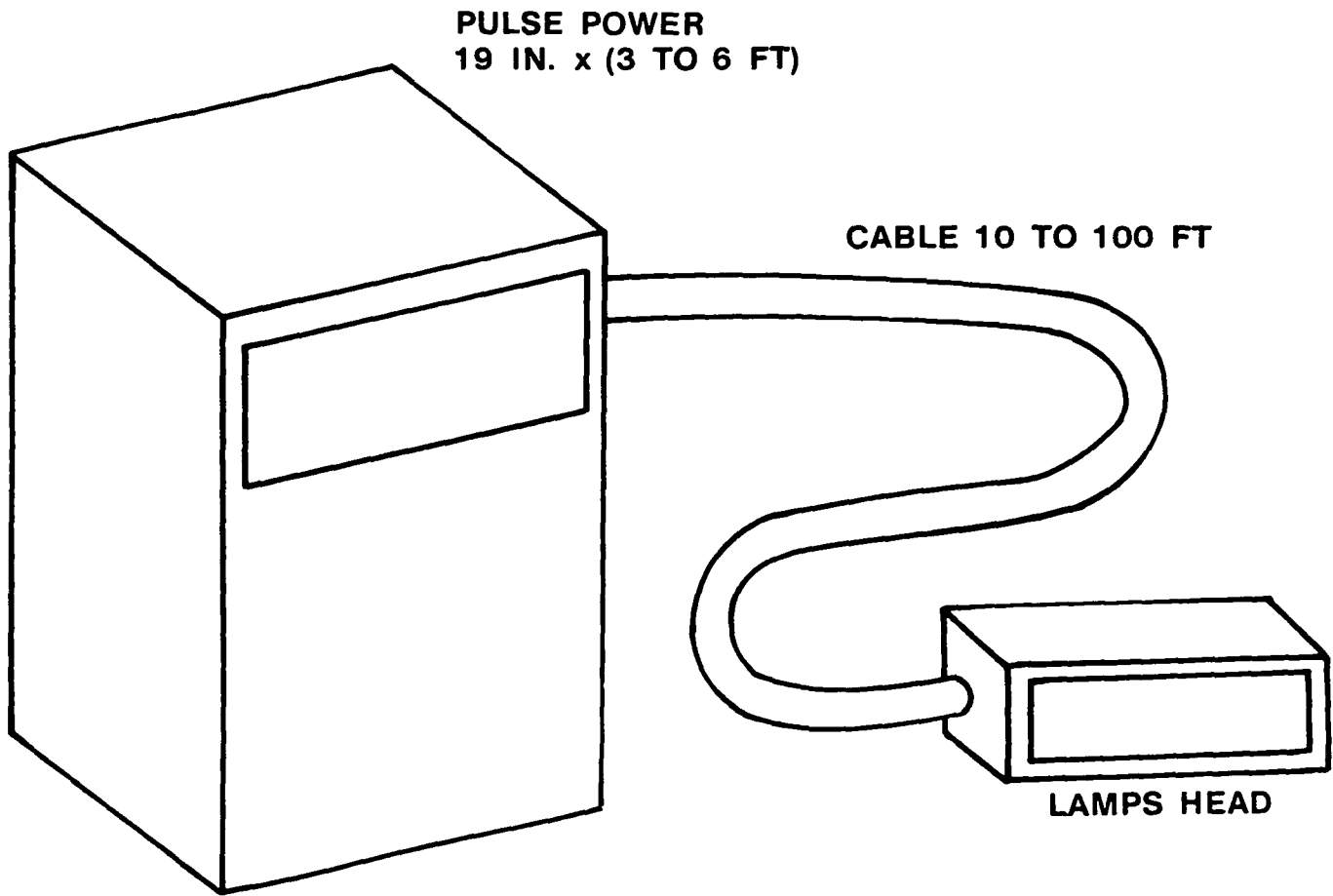


Figure 1.—Typical Flashblast system layout.

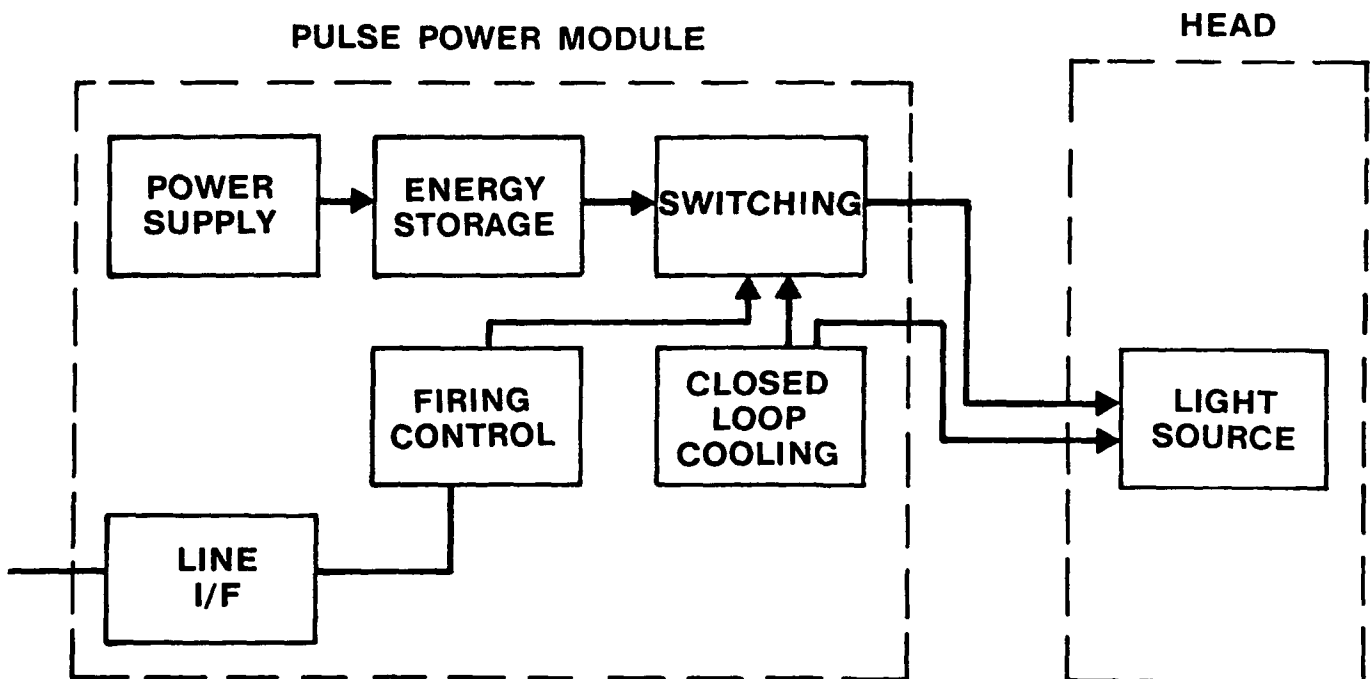


Figure 2.—Diagram of an Industrial Flashblast system.

off into the vacuum system. Conventional filters trap solid particles for safe disposal.

The sensors provide location information along with data concerning paint presence and/or thickness. A logic control unit sensor inputs to move the robotic arm and select the combination of flashlamp and CO<sub>2</sub> pellets that will remove the paint and clean the surface effectively.

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## Demonstration of Flashblast Technology

The U.S. Air Force conducted an investigation of the Xenon flashlamp depainting system, with the following conclusions:

- Residue is minimal,
- No residue gets into aircraft or avionics,
- Aircraft do not have to be masked,
- Depainted surfaces are ready for new paint,
- Coatings are removed without damaging substrate,
- The system can be used for metals and composites, and it has potential for stripping down to the primer.

Recently, Maxwell Laboratories tested a hybrid Flashblast-CO<sub>2</sub> pellet blast paint stripping procedure. These trials proved the complementary nature of the two cleaning technologies.

Additional testing is underway to determine optimum cleaning parameters for a variety of paints and substrates. Maxwell's next set of demonstrations will be conducted with improved Flashblast equipment to demonstrate paint removal at a rate of 10 square feet per minute.

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## Conclusion

Maxwell Laboratories believes that the hybrid Flashblast-CO<sub>2</sub> pellet blast approach is the best low-risk alternative for cost effectively removing paint from aircraft. Several of the system's characteristics that support this assertion include:

- No physical contact to treated surface;
- No chemicals or abrasive materials used;
- Full control of penetration depth and treated layers;
- Control of spectrum, intensity, and pulse shape;
- Easily interfaced into industrial environments and automatic systems; and
- High throughput values for surface treatment.

# The Polygon Paint Removal System

**David Van Alstyne**

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## Abstract

The Polygon Paint Removal System (PPRS) referred to in this paper is a self-contained coating's removal unit. This Xenon Flashlamp works on the same principle as the flash attachment on a camera but produces light that is several thousand times more intense. An electric current is discharged through xenon gases in the lamp. These gases absorb energy and subsequently release the energy as photons (light).

The wavelength of the emitted light can be controlled to a certain degree by controlling the gas composition and pressure inside the lamp, the discharge voltage, and the composition of the reflective material behind the lamp inside of the head. Exerting one or more of the controls, the operator of the PPRS is able to adjust the light's wavelength for optimum removal rates of specific generic paints.

The light of the xenon flashlamp is pulsed for a matter of microseconds. In this time, the coating is burned without melting. The by-product of fine ash and gases is simultaneously trapped in a vacuum/filtration system and drawn through an appendage into a containment unit. The substrate undergoes minimal heating. In one study at McClellan Air Force Base, Sacramento, CA, February 28, 1987, substrate temperatures increased from 30 to 50°F (17 to 28°C) during paint removal.

The main components for the PPRS include a power source (220 VAC), a pulse-forming network

and a controller housed in a console, and a lamp head or housing. The controller at the console allows adjustment of power, pulse rates, and on-off controls.

The hand-held head is connected to the console by an umbilical in length of up to 250 feet from its power supply. The head is also fitted with a vacuum and to a water source for cooling. Inside the head and around the xenon lamp is a reflective surface that focuses the light flash on the substrate.

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## Introduction

With the present and projected demands on the handling and disposal of hazardous wastes, compounded with the fact that fewer landfills are able to accommodate such environmental contaminants, costs have escalated. The liabilities associated with these waste treatments are an added burden. All of the readily available surface preparation methods entail the use of chemicals or blasting. Both of which require labor intensive preparatory and cleanup work.

As a result of these time consuming processes, workers with specialized skills are taken off of their designated jobs to accommodate these needs. A representation of this costly labor is demonstrated by large airlines using highly paid engine mechanics to strip aircraft.

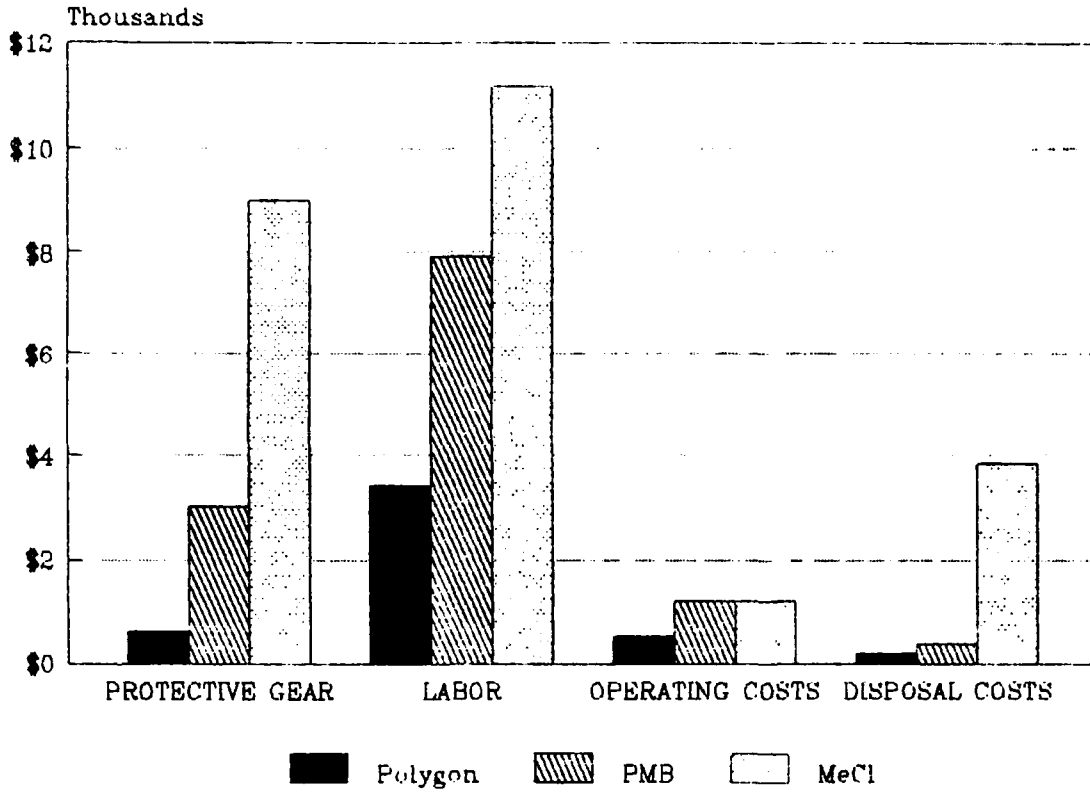


Figure 1.—Stripping costs per L10-11.

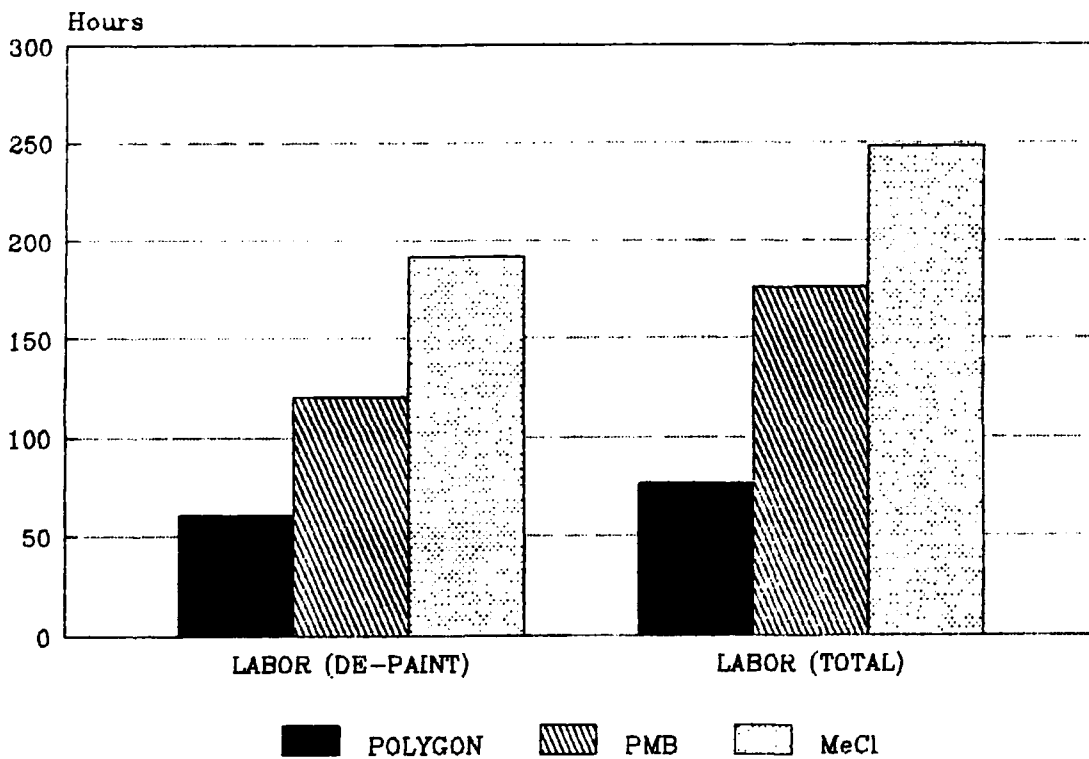


Figure 2.—Stripping labor per L10-11.

**Table 1.—A display of cost and time involved in the PPRS, PMB and methylene chloride methods of removal for 2 1/3 mils thick polyurethane topcoat and a Type 2 epoxy primer, on a L10-11 series aircraft, with a removal area of 9,115 sq. ft.**

	PPRS	PMB	MeCL
Protective wear	\$600	\$3,000	\$9,000
Operational costs	\$217	\$1,200	\$1,200
Containment	0	Total housing	Total housing
Manhours	76	176	248
Cost of manhours	\$3,420	\$7,920	\$11,160
Amount of waste produced	100 lbs. dry waste	200 lbs. dry waste	285 gals. wet waste
Cost of waste disposal	\$180	\$360	\$3,840
Total cost (excluding containment)	\$4,717	\$12,480	\$25,200

**Table 2.—The PPRS coating's removal cost/time analysis of a L10-11.**

Using the PPRS method to demonstrate the cost and time involved in the coating's removal of an L10-11 series aircraft, with a removal area of 9,115 sq. ft., 2 1/3 mils thick polyurethane topcoat, and a 2 1/3 mils thick Type 2 epoxy primer, the following rates are provided based on two PPRS units, two workers per unit.

<b>Protective wear (eye, ear, and gloves):</b>	4 people @ \$150 each	= \$600
<b>Labor (prep):</b>	4 people 4 hrs. per person 1/2 shift	= 16 hrs. X \$45 per hour = \$720
<b>Labor (strip):</b>	4 people 12 hrs. per person 1 1/2 shift	= 48 hrs./60 hrs.* X \$45 per hour = \$2,160/\$2,700*

\*Time allotted for adjustments of scaffolding and workers. Containment structure used: no containment needed.

Amortized the investment cost of \$250,000 per PPRS unit over 3 years being 1,095 days, 16 hrs. (two shifts) a day, to arrive at the hourly rate.

<b>Operational costs:</b>	Hourly rate of the PPRS	= \$14.26
	Total hrs. 24 (12 per unit)	\$342.24
	Over half of 1 lamp life	+ \$170.00
	Electricity \$.20 per hr.	+ \$4.80
		= \$517.04

**Removal rate:** 2 inches per second at 6 hz. 382.5 sq. ft. per hr. per unit

**Waste produced:** 100 lbs. dry waste

Due to the varying weights of the different colored coatings used on aircraft, we took an average of the costs and weights.

<b>Cost of disposal:</b>	=	\$180.00
<b>Total manhours:</b>	-	64 hrs./76 hrs.*
<b>Total cost:</b>		\$4,177/ \$4,717*

**Table 3.—Return on Investment over three years, 60 aircraft per year.**

Comparing the cost of methylene chloride stripping per L10-11 series aircraft at \$25,200 to the cost of the PPRS stripping per L10-11 series aircraft at \$4,717 plus the initial investment of \$500,000 for two PPRS units.

	Number of aircraft	MeCL	Polygon
<b>Year 1</b>			
	1	\$25,200	\$504,717
	5	\$126,000	\$523,585
	10	\$252,000	\$547,170
	15	\$378,000	\$570,755
	20	\$504,000	\$594,340
	*30	\$756,000	\$641,510
	40	\$1,008,000	\$688,680
	50	\$1,260,000	\$735,850
	60	\$1,512,000	\$783,020
			+ \$7,454.12 in parts
			= \$790,474.12
<b>Year 2</b>			
	80	\$2,016,000	\$884,814.12
	100	\$2,520,000	\$979,154.12
	120	\$3,024,000	\$1,073,494.12
			+ \$7,454.12 in parts
			= \$1,080,948.24
<b>Year 3</b>			
	140	\$3,528,000	\$1,175,288.24
	160	\$4,032,000	\$1,269,628.24
	180	\$4,536,000	\$1,363,968.24
			+ \$7,454.12 in parts
			= \$1,371,422.36
		<b>Savings:</b>	<b>\$3,164,577.64</b>

\* Approximate payback @ 23 planes.

**ACKNOWLEDGEMENT:** Mark Cohen and Christa Chiacos helped compile the data presented in this paper.

# Automated Laser Paint Stripping

**Paul Lovoi**

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## Introduction

Automated laser paint stripping has been identified as a technique for removing coatings from aircraft surfaces. In December 1989, International Technical Associates (InTA) was awarded Navy contract No. N00600-90-C-0281 for an automated laser paint stripping system (ALPS) that will remove paint from metallic and composite substrates. For the program, which will validate laser paint stripping, InTA will design, build, test, and install a system for fighter-size aircraft at both the Cherry Point and Norfolk Naval Aviation depots.

The program is divided into four phases:

- **Phase I:** validation testing and parametrization.
- **Phase II:** engineering design.
- **Phase III:** system fabrication and factory acceptance, and
- **Phase IV:** installation, testing, training, and final acceptance.

The Phase I test plan is divided into two parts, Phases Ia and Ib. A laser test lab has been assembled and preliminary testing carried out. The original test matrix of substrates, coatings, and testing was extensively revised during the last eight months to ensure inclusion of all the needs of both the weapon system managers and the material and structure groups.

During this process, InTA identified the need for a small initial parametrization study, along with physical testing (Phase Ia) of a small subset of stripped samples. This subset of tests would look at such physical parameters as paint surface conditions after partial stripping, paint internal structure after partial stripping, composite damage after overstripping, and paint adhesion from partially stripped surfaces. The Ia test matrix

consists of the most common coating and substrate combinations and is centered around physical tests such as microsections, scanning electron microscope (SEM), and optical microscopy.

Phase Ib, the larger test matrix, covers 15 substrate coating combinations and a total of 3,779 tests. The Air Force and Army have contributed requirements to this matrix and will fund service-specific tasks under the Navy contract.

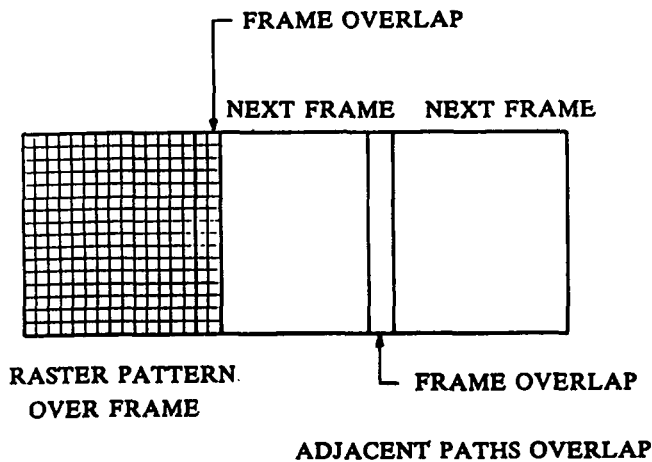
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## ALPS Technology

The InTA approach to ALPS is best described by starting with the actual removal of paint, which is done by a pulsed carbon dioxide laser with high peak power. Since very high peak powers produce plasma detonation waves in material, they are not used. Low peak power or continuous wave lasers are not used because of significant substrate heating. This process removes between 150 and 300 micro inches of coating per pulse, depending on the type of coating. During the paint removal process, the duration of the laser's energy and pulse does not vary, thus simplifying the design.

The next step is to decide whether the laser should be pulsed at a given location. A spectrograph—an instrument that divides light into different colors—is used to examine the color of the surface before the laser is fired. Colors can range from near ultraviolet to near infrared, covering all visible wavelengths. The spectra of colors to be removed are stored in a computer and compared to the spectra from the coating. If they match, the laser is pulsed, a small amount of paint removed, and the color is reexamined. This process continues until the color no longer matches the one stored in the computer.

Rather than working on one area to remove all the paint, the laser moves on and, after each area is examined, a pulse is applied or not, as neces-



PATH COMPOSED OF FRAMES

Figure 1.—A series of frames.

sary. This is called "rastering." The raster pattern covers a 30 by 30 centimeter area, called a "frame," that consists of 30 rows by 30 columns (see Fig. 1). Rastering allows each area to cool before being processed again, which is especially important for coatings like sealants and on composite sub-

strates. Once a frame is clean of any color paint whose spectra was stored in the computer, the system commands the robot to move to a new frame.

The aircraft to be stripped is mapped into a series of paths consisting of adjacent frames. To ensure that all the paint on the aircraft is removed and no lines or bands of paint remain between frames, the frames are overlapped, which removes the need for a precision robot.

To get the laser and end effector to all parts of the aircraft, InTA developed a long reach, flexible robot system mounted on an air-bearing platform that moves from one area to another. This reduces the reach required of the robot and provides flexibility for new aircraft and extension of the technology to larger planes. A pictorial of the system components is shown in Figure 2.

The material removed from the aircraft is vacuumed up as it is created and sent to a waste processor, which separates the waste into particulate material and vapors. The particulates are filtered out, dried, and placed in storage containers (Fig. 3). The vapors are oxidized and converted to

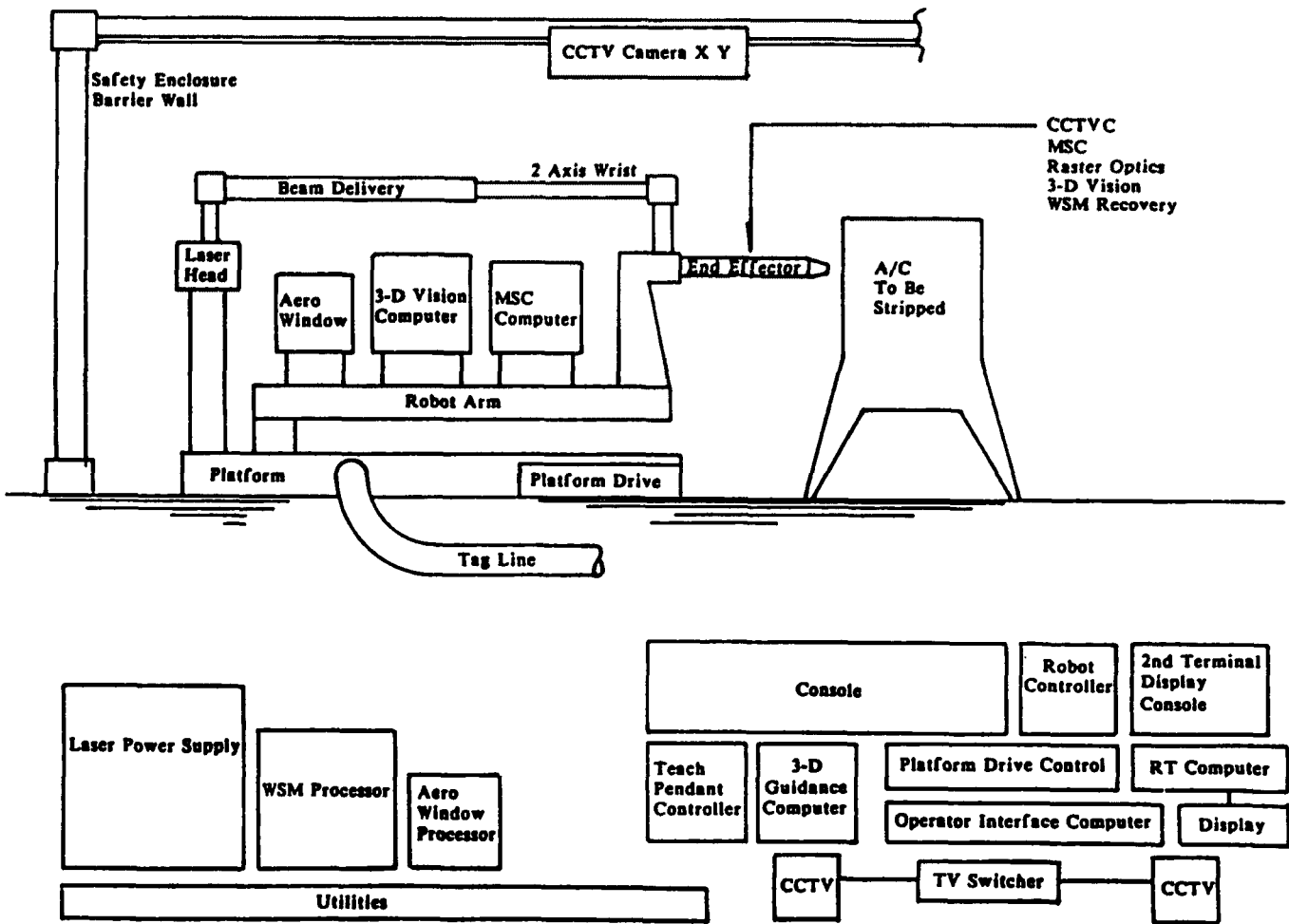


Figure 2.—Components of the ALPS system.

## WASTE MANAGEMENT

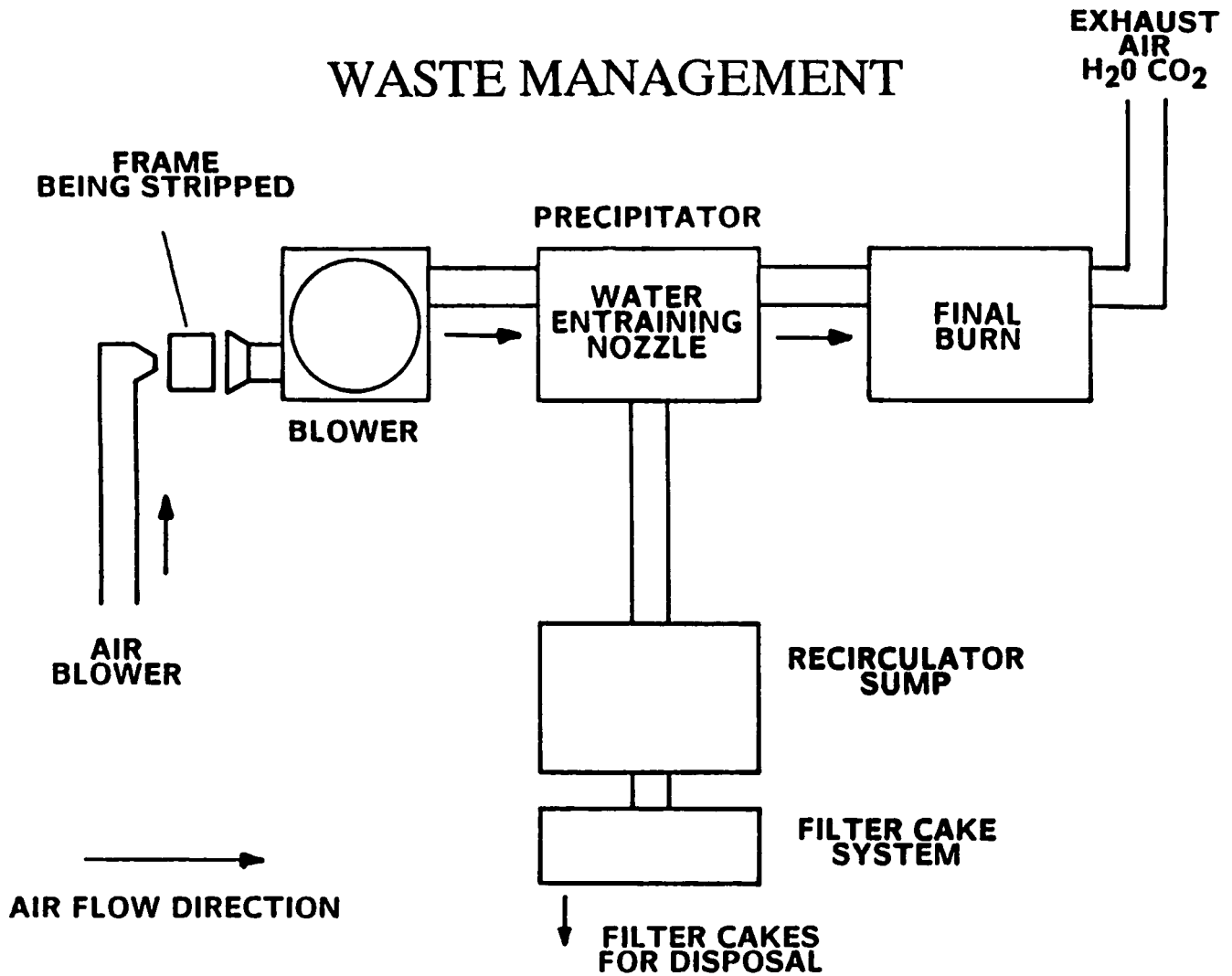


Figure 3.—The layout of the waste stream processing system.

carbon dioxide, nitrogen, and water vapor, safe disposal forms that meet federal, state, and local laws.

### Present Program Status

A screening and optimization test matrix has been prepared to assess laser paint stripping's technical capability to remove organic coatings from aircraft exterior surfaces. This matrix, which originally included test requirements identified by Grum-

man Aerospace Corporation's Engineering Department, has been extensively modified. The revised matrix has been approved by NAVAIR materials and structures engineers as well as those at the Cherry Point and Norfolk Naval Aviation depots.

The Phase Ia metallic and composite samples have been stripped and sent to Grumman Aerospace Corporation for testing and recoating. Phase Ia will be completed by the second quarter of 1991. The test panels for Phase Ib have been fabricated.

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# **MAINTENANCE PAINT STRIPPING**

***Exposure Control &  
Pollution Prevention***

**Chair: James Gideon**  
*Division of Physical Sciences and Engineering  
National Institute for Occupational Safety and Health*

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# Waste Minimization for Army Depot Paint Stripping Operations

**Ronald P. Jackson, Jr.**

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Toxic and Hazardous Materials Agency  
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## Introduction

U.S. Army depots perform the overhaul and repair of tactical equipment. Typical depot maintenance operations include metal pretreatment (cleaning, degreasing, removal of surface coatings) and metal finishing (electroplating, conversion coating, paint application) processes. Large amounts of hazardous waste and air pollutants are generated during these operations. Control, treatment, and waste materials disposal are expensive and often difficult.

Paint removal processes are a major source of waste generation at Army maintenance installations. These operations produce many tons yearly as exhausted solvents, spent blast media, wastewater, sludges, and air pollutants. Consequently, depot facilities are attempting to prevent the generation of waste materials at the source. This approach reduces the amount that must be tracked, treated, and disposed of and can result in significant cost savings to the installations. Source reduction also diminishes the long-term liability associated with the generation of hazardous materials.

The U.S. Army Toxic and Hazardous Materials Agency (USATHAMA) conducts the Pollution Abatement and Environmental Control Technology (PAECT) program that includes assisting depots achieve their hazardous waste minimization (HAZMIN) goals. The program performs research and development leading to adoption of technology that is required for compliance with environmental regulations; will result in significant cost/energy savings in comparison with existing technology; and will allow for minimization, recycling, recovery, and reuse of wastes or excess material in a cost-effective manner. Currently, USATHAMA is evaluating modifications to

existing depot paint removal processes as well as commercially available, state-of-the-art technologies that are more economical and efficient than existing methods.

The paint removal method used depends on the type of tactical equipment being processed and often varies among depots. This paper discusses the techniques employed by Army facilities and measures being taken to minimize waste from paint stripping operations.

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## Abrasive Paint Stripping Operations

A wide variety of abrasive blast media are used during equipment maintenance operations at depot facilities. Types of materials employed include walnut shells, steel shot, aluminum oxide, peridot, sand, glass, and plastic beads. Spent media are usually disposed of as hazardous waste because of heavy metal contamination from paint pigments and surface finishes removed from the equipment being processed.

Depots are attempting to minimize waste generation by using media with longer usable lives. For example, sand is relatively cheap but fractures easily. The medium is also an environmental hygiene concern. Peridot is slightly more expensive but cost competitive with sand because it is more durable and recyclable. Steel shot is several times more expensive than sand; however, it is one of the most effective media in terms of cost-per-unit of surface depainted. It is extremely durable and can be reused as many as 50 to 100 times. However, steel shot damages sensitive substrates and machined surfaces. Plastic beads have been shown to be more recyclable than most other types of blast media and do not damage sensitive substrates such as aluminum.

## **Plastic Media Blasting**

In 1988, USATHAMA conducted demonstration testing of plastic media blasting (PMB) at Letterkenny Army Depot (Chambersburg, Pennsylvania) to assist depots in implementing the process. Plastic was compared to agricultural blast media (walnut shells) and glass beads to determine if PMB was a cost-effective alternative. Results of the test program showed that plastic media paint removal rates were similar to walnut shells when performed at optimum operating conditions. Media consumption (waste generation) rates for PMB were about 50 percent lower than those of agricultural media blasting (AMB). However, overall depainting costs for PMB were 20-to-30 percent higher than AMB.

All media tested proved capable of removing chemical agent resistant coatings (CARC). However, neither plastic nor walnut shells removed deeply pitted corrosion. A combination of 80 percent plastic and 20 percent glass beads successfully removed corrosion but decreased paint removal rates about 30 percent.

Many depot installations have implemented plastic media blasting. Recent reevaluations of paint removal rates indicate that PMB is about 35 percent slower than agricultural media blasting. The low media consumption rate of PMB is offset by the additional time required to completely remove surface coatings. Consequently, some depots have reported that implementation of PMB has not significantly reduced overall waste generation. Several depots are investigating ways to reclaim the exhausted plastic media to further reduce high operational costs and decrease the amount of disposable waste.

## **Other Alternative Blasting Methods**

The Joint Technology Exchange Group (JTEG), a triservice advisory body, identifies new technology or processes with the potential to improve the efficiency of Department of Defense depot installations. Several paint removal processes are currently being evaluated by JTEG, including high-pressure water, sodium bicarbonate blasting, carbon dioxide pellets, and plastic media blasting.

Sodium bicarbonate blasting removal rates are slower than those of the blast media currently used at Army depots. The process will generate sludge that may require treatment and/or disposal as hazardous waste. Another potential drawback is that sodium bicarbonate may corrode some metallic substrates.

Carbon dioxide blasting, a relatively clean process, is much slower than current paint removal methods and may not effectively remove chemical agent resistant coatings. The possibility of damage to substrates from thermal shock is also a major concern. However, the process may be a waste reduction technique for cleaning and degreasing operations requiring the use of chlorinated solvents.

Neither sodium bicarbonate nor carbon dioxide blasting is considered a viable alternative depainting technique for Army depot operations at the present time. USATHAMA will continue to monitor JTEG's test programs with respect to their applicability for Army use.

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## **Chemical Paint Stripping Operations**

Although the removal of paint from tactical equipment is accomplished with other techniques, chemical stripping is currently the most cost-effective method for small, complex parts. Typically, the equipment to be stripped is disassembled before processing. The smaller parts are loaded into a basket and placed in a dip tank containing the stripping solution. This method generates large amounts of hazardous waste as spent solvents, wastewater, and paint sludge. Additionally, paint strippers are a source of total toxic organic (TTO) and volatile organic compound (VOC) emissions.

The U.S. Army Depot Systems Command (DESCOM) has established a goal of zero generation for six major waste streams, including chemical paint removal. Letterkenny Army Depot has been designated as the Center for Technical Excellence (CTX) for chemical paint stripping. As the CTX, Letterkenny is the lead depot for identifying methods to achieve the DESCOM goal. Some techniques being investigated include replacing strippers containing hazardous materials, increasing the lives of strippers, and decreasing sludge generation.

## **Alternate Chemical Paint Strippers**

In 1986, the U.S. Environmental Protection Agency enacted new discharge criteria regulating the amount of total toxic organic emitted from metals finishing facilities. The maximum allowable total toxic organic was established as 2.13 mg/L for facilities discharging 10,000 or more gallons of process wastewater per day. At Army depot installations, chemical paint stripping operations con-

tribute approximately 90 percent of the TTO emissions. A significant contributor is methylene chloride, the active component in the Army's standard chemical stripping formulation.

Methylene chloride is used in stripping operations because it can remove almost all types of paints, including chemical agent resistant coatings, relatively quickly without damaging the metal substrates. However, the compound is a suspected carcinogen and a major contributor of VOC emissions. Additionally, disposal of methylene chloride wastes is expensive and often difficult.

The U.S. Army Construction Engineering Laboratory (USACERL) is completing a study for USATHAMA to identify and evaluate the performance of commercially available alternate chemical strippers. The project's objectives are to establish stripping efficiency; alleviate total toxic organic compliance problems; and assess the health, safety, and environmental hazards of the identified formulations. The study's results will be available in August 1991.

A three-phase approach was used to achieve this test program's objectives. Approximately 30 formulations were laboratory tested for acceptable performance during the study's first phase. The major performance criterion for laboratory screenings was to strip a wide range of surface coatings within two hours. The six strippers that met the stripping performance standard were subjected to pilot-scale testing at Sacramento Army Depot (California). Several other criteria were considered during the test program's second phase, including effects on worker safety, presence of TTO-contributing compounds or other hazardous materials, compatibility with metal substrates, ease of disposal, and cost effectiveness.

The three most promising strippers from the second phase were selected for demonstration testing on a depot production line. The strippers use an oil seal to retard evaporation, are of a similar formulation, and require elevated operating temperatures. The first stripper's evaluation was completed in 1989. The solution was plagued by a high evaporation rate and stopped working after only six months. The second formulation is presently being evaluated at Sacramento Army Depot. The stripper is evaporating at the rate of approximately 100 gallons per month, which results in monthly materials cost of about \$3,000. The third stripper, currently used in operations at Red River Army Depot (Texarkana, Texas), also has an unacceptably high evaporation rate. Both candidates do not remove all required surface coatings

and have operational costs at least two-to-three times greater than methylene chloride-based strippers. All three formulations require disposal as hazardous wastes, which will further increase overall operational costs.

### ***Filtration of an Alkaline Paint Stripper***

Alkaline paint strippers are also employed during depot surface removal operations. Over time, an alkaline stripping solution will lose its strength because some of the paint residue initially removed from parts continues to react with the active reagents. This residue settles and forms a layer of sludge at the bottom of the bath. Additional reagents must be added periodically to restore stripping performance. Eventually, the sludge buildup limits the bath's working depth, and the addition of reagents becomes so frequent that replacing the solution is more cost effective. The spent stripper and sludge must then be disposed of as hazardous waste. Removing paint residues from the solution may prolong bath lives, lessen the number of tank changes, and reduce the number of waste materials.

USATHAMA is evaluating the use of a filtration system to expand the life of a sodium hydroxide-based stripper at Letterkenny Army Depot. This study's information will be used to recommend methods to improve filtration or identify other ways to extend the lives of chemical paint strippers. The study's final report will be available in June 1991.

The filtration system is being tested on a dip tank containing approximately 3,000 gallons of solution. Without filtration, the tank must be replaced every four to six months. Each tank change generates about 1,000 gallons of hazardous waste that must be disposed of at a cost of \$5.50 per gallon. Additionally, refilling the tank requires approximately \$11,000 worth of reagent. Removing the paint residue from the stripping bath may extend the solution's useful life two to three times. The increase in bath life will drastically reduce waste generation and overall operational costs.

The filtration system cost approximately \$25,000 and has been operational since January 1991. The unit consists of three filter housings in series (Fig. 1) currently fitted with 50, 100, and 400 micron bags. The bags are presently emptied at least twice a week and can be reused several times. The bag sizes and changing frequency will be adjusted as the test program progresses. The sludge is dewatered and collected in a 55-gallon

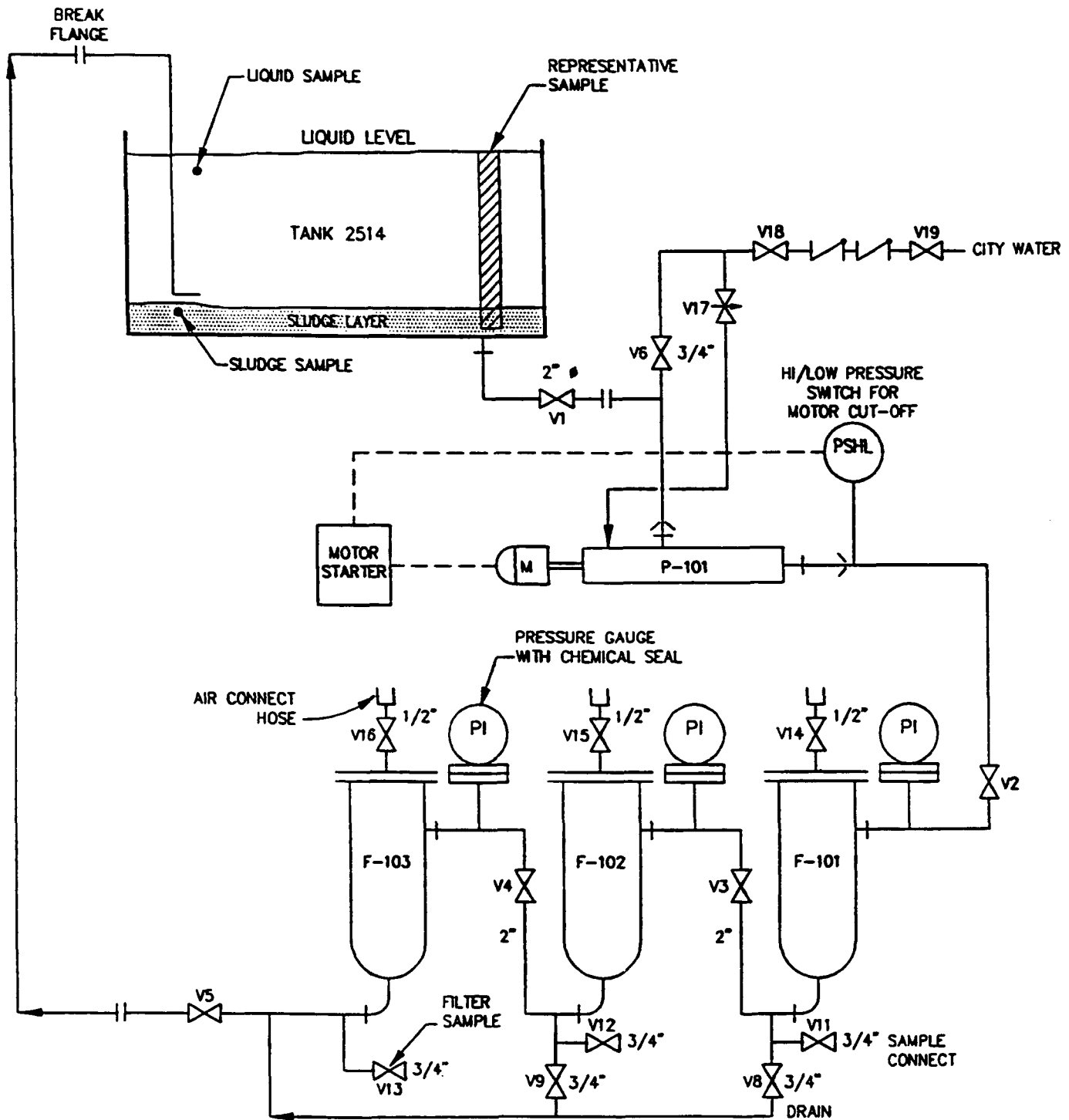


Figure 1.—Process sketch for the alkaline paint stripping solution particulate filtration system.

drum as hazardous waste. A progressive cavity pump is used to circulate the stripper bath's contents at 50 gallons per minute.

During the test program's preliminary phase, the tank was sampled three times over a 44-day period and factors affecting its life span were studied. Solids settling, specific gravity, alkalinity, and particle size analysis were conducted on the solution to determine the stripper's and sludge's characteristics (see Tables 1 and 2). Based on the data obtained, tank dimensions, bath life, and

known depot production rate, it is estimated that approximately 0.5–1.0 cubic feet of sludge are generated daily.

## Other Alternative Methods

Other alternative paint removal processes have been identified, including molten salt baths, high-temperature air bake ovens, heated fluidized beds, and laser energy. Fluidized bed and laser technology are described in the following section.

**Table 1.—Summary of analytical results for alkaline paint stripping solution at Letterkenny Army Depot.**

PARAMETER	SAMPLE DATE		
	MARCH 20	APRIL 12	MAY 2
Total residue (mg/L)	727,000	668,000	535,000
Filterable residue (mg/L)	1,500	2,500	9,700
Nonfilterable residue (mg/L)	726,000	665,000	525,000
Specific gravity liquid	1.34	1.30	1.23
Specific gravity sludge	NA	1.58	1.31
Alkalinity (mg/L as CaCO <sub>3</sub> )			
End point pH 8.3	NA	354,000	304,000
End point pH 4.5	NA	390,000	341,000

Source: ES&E, 1990.  
Note: NA = Not Analyzed.

**Table 2.—Summary of particle size analysis results for alkaline paint stripping solution at Letterkenny Army Depot (results reported in microns).**

PARAMETER	SAMPLE DATE		
	MARCH 20	APRIL 12	MAY 2
<b>Population data</b>			
Mean	1.646	1.293	1.822
Median	1.471	1.189	1.573
Mode	1.097	0.845	1.105
<b>Distribution</b>			
>1%	3.556	2.195	4.184
>25%	2.235	1.596	2.468
>50%	1.471	1.189	1.573
>75%	1.069	0.951	1.114
>90%	0.880	0.837	0.900
<b>Volume data</b>			
Mean	47.25	43.67	96.78
Median	58.82	64.71	108.30
Mode	85.51	159.20	143.00
<b>Distribution</b>			
>10%	150.700	225.500	251.900
>25%	95.920	143.800	178.300
>50%	58.820	64.710	108.300
>75%	27.580	16.830	58.540
>90%	9.834	3.791	32.680

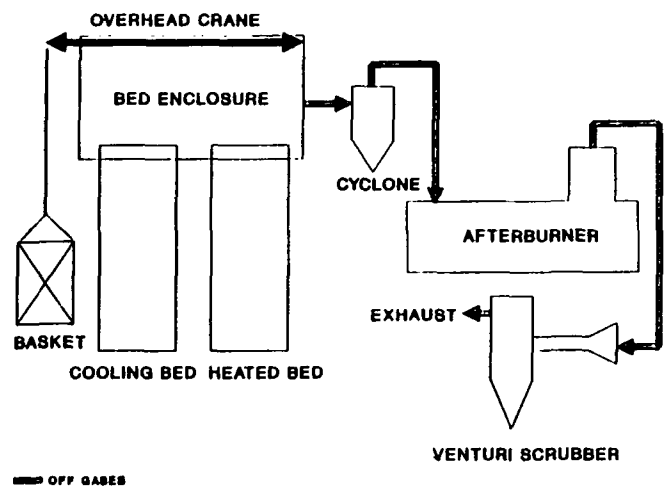
Source: ESE, 1990.

### Fluidized Bed Paint Stripper and Degreaser

The feasibility of using a heated bed of fluidized aluminum oxide to remove paint and grease from tactical equipment is being demonstrated by USATHAMA at Red River and Letterkenny Army depots. The systems can remove all types of paints normally encountered, including chemical agent resistant coatings. The process is an alternative to chemical dip tanks for parts that can tolerate temperatures of 750 to 800°F. The fluidized bed can significantly decrease hazardous waste generation and provides a safer work environment.

Fluidized aluminum oxide has heat transfer characteristics approaching those of a liquid. The fluidized bed paint stripper (FBPS) uses heat transfer between the aluminum oxide and the parts undergoing processing to remove surface coatings and grease. The amount of air required

for fluidization is not sufficient to support combustion in the bed. Consequently, organic constituents of the paint are pyrolyzed to carbon and carbon monoxide while grease and oils are vaporized. The organic material is combusted in an afterburner at 1,400°F. The afterburner exhaust is passed through a Venturi scrubber during operations at Red River to remove any potential zinc, cadmium, or lead emissions before discharge to the atmosphere. Figure 2 presents a diagram of a typical FBPS unit. Any organic grit remaining on the parts after processing in the bed is removed by low-energy shot blasting.



**Figure 2.—Components of the fluidized bed paint stripper.**

The effects of high operational temperature on various types of metallic substrates will be determined during the test programs. Selected parts from the other triservices will also be processed. Data on waste generation, operational parameters, and production costs will be gathered. Reports on the FBPS demonstrations will be available in August 1991.

### Laser Depainting

Several studies indicate that paint can be removed by targeting laser energy directly onto the coating surface. Chemical agent resistant coatings, although resistant to most paint-removal systems, would be susceptible to laser degradation. However, the use of lasers will involve high capital costs because of the sophisticated equipment required. JTEG is currently evaluating the process.

### Conclusions

The Army depots are making progress toward meeting DESCOM's goal of zero hazardous waste

generation for six major waste streams, including chemical paint removal. The results of USATHAMA's and JTEG's efforts will assist the installations. However, obstacles remain, includ-

ing insufficient funding to implement proven technology, manpower shortages, and lack of technical information transfer among Army and other Department of Defense facilities.

# The Biodegradation of Paint Waste

Gail Bowers-Irons

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**A**ircraft, combat vehicles, logistic equipment, and ships require constant repair and maintenance. Typical aircraft waste generation numbers are 1.5 tons of material per C5 or C141 (cargo planes), 0.5 tons of material per F4 jet, and 0.4 tons of material per 5,000 square feet of commercial plane. Presently, current aircraft chemical stripping requires 365 man-hours, in addition to preparation and cleanup time. The chemicals are not reusable, and there is often a 20,000 gallon contaminated MEK/paint water clean-up problem.

Costs for the current process have been estimated at \$10-15/gallon per 100-200 gallon/strip job. Bead blasting requires 36 manhours combined with additional preparation and cleanup time. Both of these methods require a dry strip method to remove the residual material, predominately primer. Dry stripping requires 185 manhours per procedure. In the process of dry stripping, metal is lost. Incineration costs of dry strip material range from \$700 to \$1,000 per 55-gallon drum.

Enzymatic degradation could replace these processes. Technical Research Associates, Inc. (TRA), under a Small Business Innovative Research Phase II grant, is developing an enzymatic paint waste biodegradation system. The supporting organization is the Materials Laboratory, Wright Research and Development Center, Aeronautical Systems Division (AFSC), Wright-Patterson Air Force Base, Ohio, under contract F33615-90-C-5910. The technical monitor is Captain Gary D. Meuer.

TRA is studying mixed Type II bead/Type V bead/paint/primer wastes. The paint/primer waste samples were obtained from Tom Byers and

Owen Mitchell, Hill Air Force Base (HAFB), Utah. The Type II beads are U.S. Technology Thermoset Urea Formaldehydes. The Type V beads (Dupont L) are Thermoplastic Acrylics: stearamidopropyl-dimethyl-Beta-hydro-xyethylammonium nitrate. The bead/paint wastes contain Mil Spec polyurethane paint and chromate/strontium primer. The results of a representative paint material data safety sheet (MSDS) are shown in Table 1. Table 2 shows the results of a representative EDAX analysis.

Table 1.—Representative paint MSDS.

PRODUCT CLASS: POLYESTER	
INGREDIENT	WEIGHT PERCENT
Titanium dioxide	15.0
Amorphous silica	15.0
Carbon black	<5.0
Cyclohexanone	<5.0
Methyl ethyl ketone	15.0
Methyl isobutyl ketone	10.0
Butyl acetate	10.0

PRODUCT CLASS: POLYISOCYANATE	
INGREDIENT	WEIGHT PERCENT
Cyclohexanone	5.0
Methyl N-amyl ketone	30.0
Methyl ethyl ketone	25.0
Xylene	5.0
Aliphatic polyisocyanate	30.0
Toluene	<5.0

Table 2.—Representative EDAX analysis.

ELEMENT	WEIGHT %	ATOMIC %
Mg	5.74	13.91
Al	5.23	11.41
Ca	3.98	5.85
Ti	10.65	13.09
Cr	12.51	14.17
Sr	61.89	41.59

**Table 3.—Type II, Type V, and mixed bead/paint waste materials solubilization.**

ACID/BASE	SOLUBILITY		MIXED BEADS/PAINT
	TYPE II	TYPE V	
CH <sub>3</sub> COOH	None	None	Cloudy solution
HCL	None	None	None
HNO <sub>3</sub>	None	None	None
H <sub>3</sub> PO <sub>3</sub>	None	None	Cloudy
H <sub>2</sub> SO <sub>4</sub>	None	None	None
NH <sub>4</sub> OH	None	None	Light yellow tint
KOH	None	None	Yellow tint
NaOH	None	None	Yellow tint

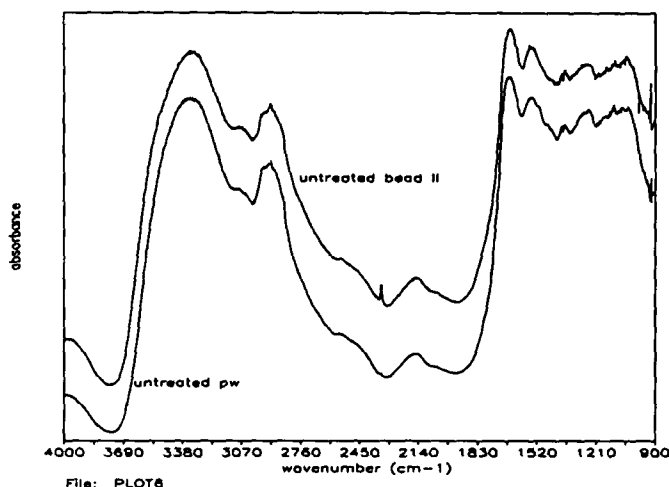
**Table 4.—Mixed bead/paint UV-Vis spectrophotometry analysis.**

ACID/BASE	WAVELENGTH	ABSORBANCE	BASELINE
CH <sub>3</sub> COOH	343 nm	0.258 A	CH <sub>3</sub> COOH
H <sub>3</sub> PO <sub>4</sub>	None	None	H <sub>3</sub> PO <sub>4</sub>
NH <sub>4</sub> OH	372 nm	1.472 A	NH <sub>4</sub> OH
KOH	370 nm	2.757 A	KOH
KOH	371 nm	2.751 A	DI H <sub>2</sub> O
NaOH	371 nm	2.656 A	NaOH
NaOH	371 nm	2.661 A	DI H <sub>2</sub> O

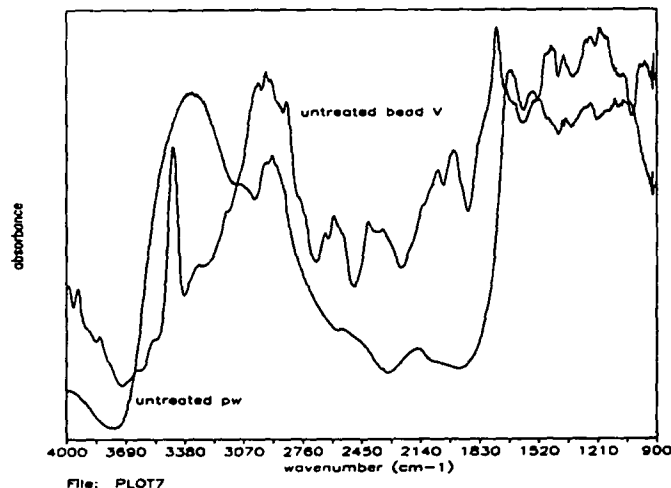
The Type II, Type V, and mixed bead/paint waste materials were placed in 1 molar acid and base solutions to test solubilization. The solubility results are shown in Table 3. Table 4 shows results of mixed beads/paint UV-Vis spectrophotometry analysis.

Biodegradation experiments now in process use a patented and American Type Culture Collection-registered (ATCC 53922) TRA culture (HAFB-1), as well as two new indigenous cultures (HAFB-2 and HAFB-3). TRA can biodegrade a 10 percent loading in less than 30 hours for a cost of less than \$28 per 55-gallon drum. TRA expects to field test a scaled, semicontinuous system at HAFB by spring 1992.

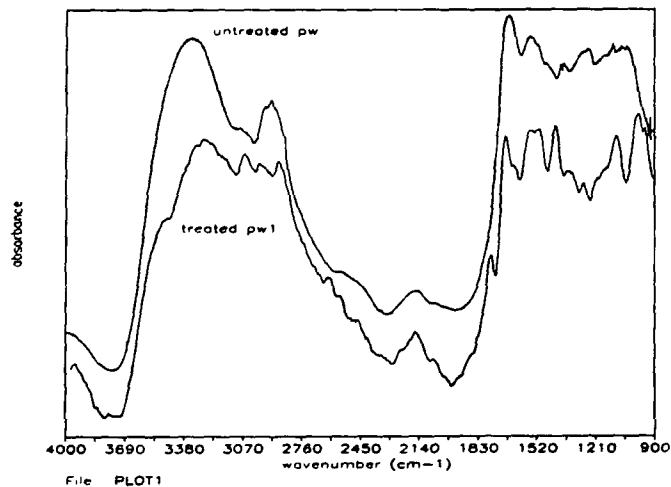
Figures 1 and 2 show FTIR scans of Type II and Type V beads, respectively, vs. mixed Type II/Type V bead/paint waste. Figure 3 is an FTIR of non-protreated biodegraded bead/paint waste vs. untreated bead/paint waste. All spectra were converted to absorbance units for the overlay. These spectra can only be interpreted qualitatively, based on the wavenumber of location and the presence or nonpresence of activities at that location. Figures 4 and 5 show UV-Vis scans of biosolubilized beads/paint waste liquor.



**Figure 1.—Fourier Transform Infrared Spectrophotometry (FTIR) scans of Type II beads/paint waste. Non-biodegradable Type II beads are predominant in these mixed Hill Air Force Base bead/paint wastes.**



**Figure 2.—FTIR scans of Type V bead/paint waste.**



**Figure 3.—FTIR scan of nonprotreated biodegraded Type II/Type V bead/paint waste vs. untreated bead/paint waste.**

# Vapor Recovery and Recycling of Methylene Chloride from Paint Stripping Applications

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## Introduction

The predominant factors affecting the costs of control technologies are the volume flow of the methylene chloride-laden airstream, and more importantly, the concentration of methylene chloride. Annual vapor emission control costs have been projected for solvent-laden airflows ranging from 1,000 cubic feet per minute (cfm) to 50,000 cfm, with airborne concentrations of methylene chloride from 100 parts per million by volume (ppmv) to 3,000 ppmv. The results of this study showed that applications above 500 ppmv would allow control costs to be kept under \$5,000 per ton of methylene chloride controlled.

The competitive technologies all used adsorption as a method to remove methylene chloride vapor from the solvent-laden airstream and concentrate it; however, their methods to regenerate the adsorption bed differed. The three technologies evaluated were:

- Adsorption with steam regeneration,
- Adsorption with inert gas regeneration that uses a reverse Brayton cycle condensation system, and
- Adsorption with "decoupled" inert gas regeneration that uses a reverse Brayton cycle condensation system.

A "decoupled" inert gas regeneration system can be physically separated from the adsorption side of the vapor recovery equipment. Since the regeneration (desorption) equipment is mobile, it can be transported from one adsorption concentrator to another. Therefore, the cost of the regeneration equipment is shared among many adsorption control devices and locations.

Other technologies that are technically feasible, such as the destruction of methylene chloride by incineration, direct condensation of the vapors from the solvent-laden airstream (using a reverse Rankine or Brayton cycle), and off-site reactivation of adsorbents were screened in the preliminary stages of the study and not found cost-competitive, under the previously discussed conditions.

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## Competitive Technologies

### *Adsorption with Steam Regeneration*

Figure 1 shows a typical steam-regenerated adsorption system that could be applied to control methylene chloride emissions. Solvent vapors are collected on the adsorbent (assumed to be activated carbon in this study) and periodically the adsorbent is regenerated with steam. The equipment consists of a steam boiler, at least two

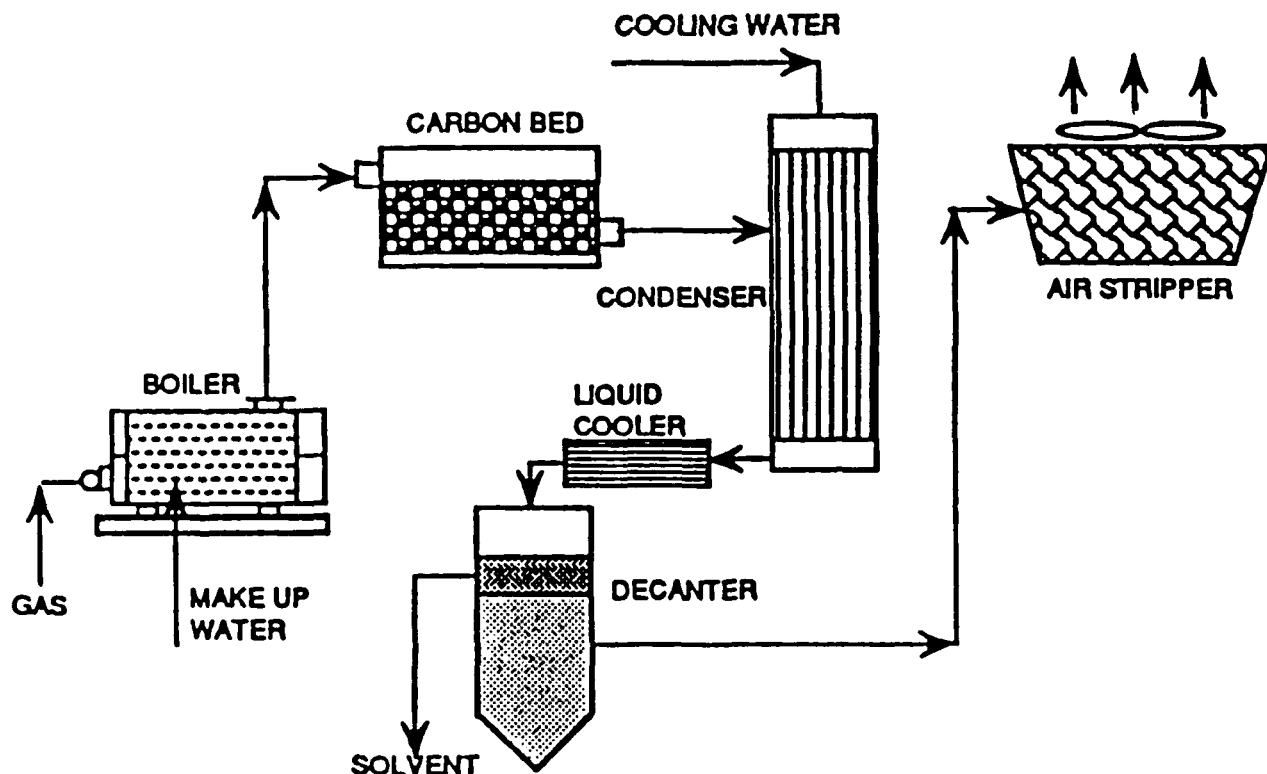


Figure 1.—Steam regeneration system with decanting solvent and water separation.

separate adsorbers (one adsorber is adsorbing while the other is being regenerated), a blower to circulate the solvent-laden airflow through the adsorbers, condenser, separator, decanting system to separate the steam condensate from the recovered solvents, and an air stripper to clean the steam condensate.

Since methylene chloride is slightly miscible with water, the decanting process does not remove it completely; however, air stripping takes the remaining methylene chloride from the condensate. Then the cleaned condensate can be returned to the boiler or discharged to the environment. The air discharged from the stripper is returned to the adsorbers to prevent discharge of methylene chloride-laden emissions.

### Adsorption with "Coupled" Brayton Cycle Inert Gas Regeneration

Figure 2 shows an inert (nitrogen) gas regenerated adsorption system that uses a reverse Brayton cycle to condense vapors. Solvent vapors are collected on the adsorption bed in the same manner as the steam-regenerated system; the difference lies in the length of the adsorption and regeneration cycle of the adsorbers and in the use of an inert gas in place of steam. Step-by-step, the inert gas regeneration process:

- Strips the solvents from the adsorber with hot (above 300°F) inert gas,
- Condenses the solvent vapors from the solvent-laden inert gas stream by chilling to extremely low temperatures (-100°F) with a reverse Brayton cycle, and
- Returns the essentially solvent-free hot inert gas to the adsorber for further regeneration.

### Adsorption with "Decoupled" Brayton Cycle Gas Regeneration

This method physically separates inert gas regeneration system from the adsorbers. Therefore, the equipment components are essentially the same as those shown in Figure 2, but the adsorbers and the solvent-laden air blower are stationed at the emission source and the inert gas regeneration system is mobile and can be "decoupled" from the adsorbers (see Fig. 3). In this way, the reverse Brayton cycle inert gas regeneration system can serve many adsorbers at geographically different industrial sites.

The reverse Brayton cycle produces low gas stream temperatures by removing heat with a low

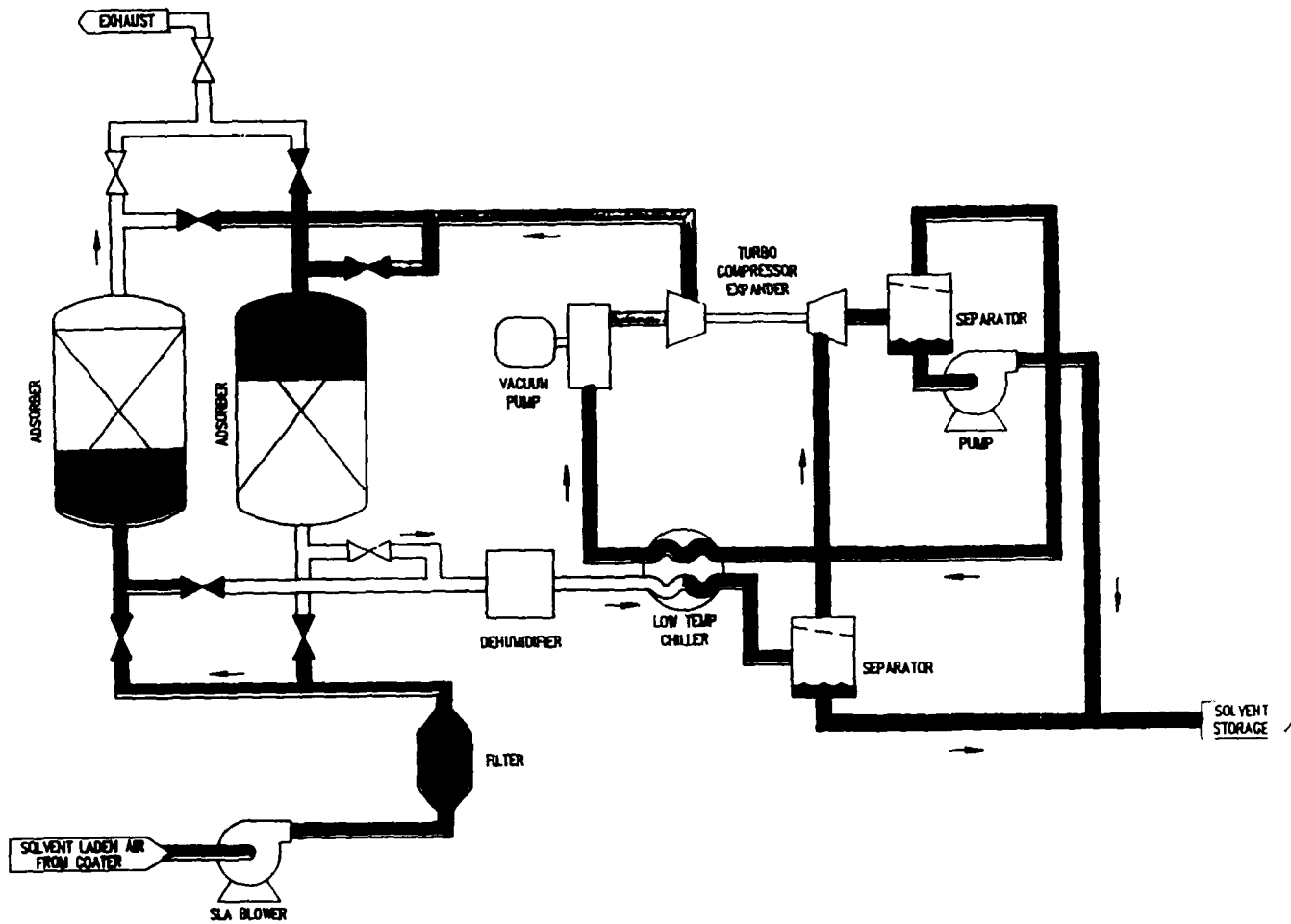


Figure 2.—"Coupled" Brayton cycle inert gas regeneration system (courtesy of Nucon International, Inc.).

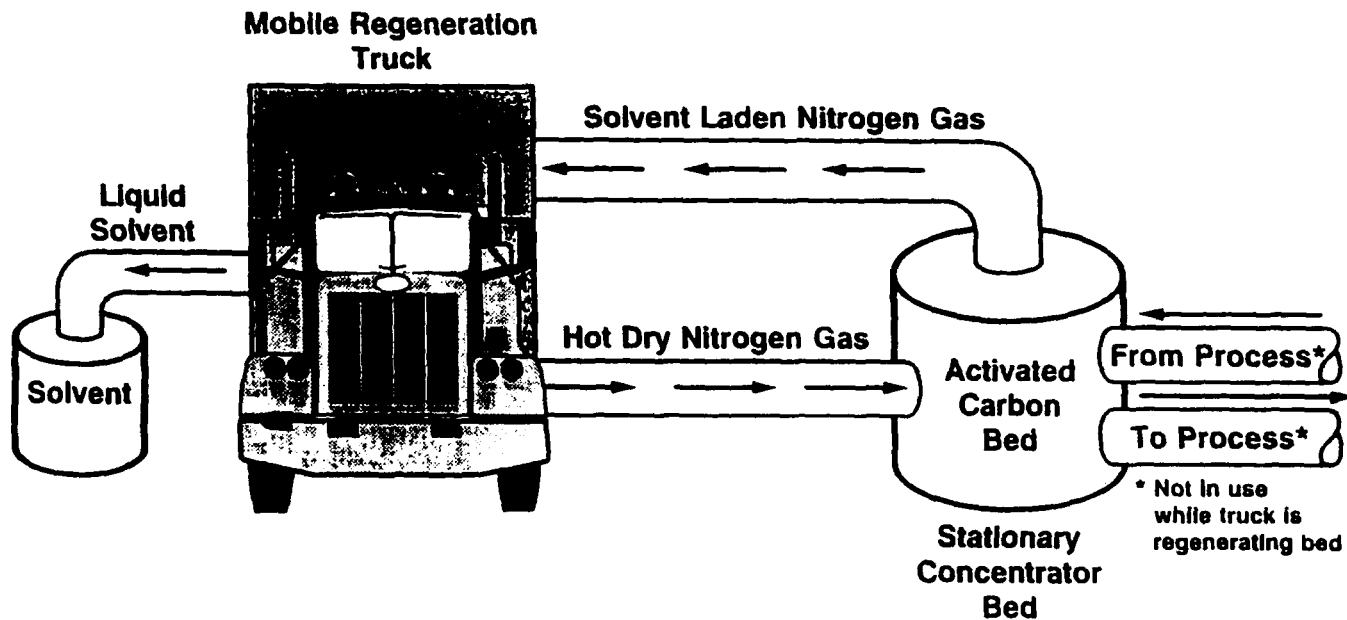


Figure 3.—"Decoupled" Brayton cycle inert gas regeneration system.

temperature chiller heat exchanger (heat regeneration); extracting work energy from the gas stream with a turbo-expander to cool it; regenerating heat from the cold gas stream by passing it on

the other side of the low temperature chiller again; then compressing, and thus heating, the gas stream with a turbo-compressor that is driven by the turbo-expander and a motor-driven vacuum

compressor. The gas stream containing solvent vapors is cooled significantly enough to condense a majority of the vapors. Also, it is heated by compression to a temperature level (above 300°F) satisfactory for inert gas adsorption bed stripping without supplemental heating.

In the case of methylene chloride, the inert gas stream must be cooled to -150°F to remove a majority (99 percent) of the very low boiling point solvent. Since the reverse Brayton cycle can reach a low condensation temperature in a single stage of turbo compression and expansion, it is a good method to recover methylene chloride.

Critical components of this system are two separate adsorbers with a solvent-laden airblower, and the reverse Brayton cycle regeneration system, which consists of a dehumidifier, a motor-driven vacuum compressor, a turbo compressor-expander, a low temperature chiller (regenerative heat exchanger), two separators, and a pump for circulating the recovered liquid solvent.

## Vapor Recovery Control Cost Estimations

The primary influences on the cost of the three vapor recovery technologies are the volume flow of the solvent-laden airstream and the concentration of the methylene chloride within it. For purposes of evaluation, it was assumed that paint stripping applications produce airstreams laden with methylene chloride solvent concentrations under 3,000 ppmv and the volume flow ranged between 1,000 and 50,000 cfm. Many of the paint stripping applications have concentrations under 100

ppmv. However, for applications with very low concentrations (under 100 ppmv), the cost to control these emissions by recovery is exceedingly high—greater than \$10,000 per ton of solvent controlled. Therefore, vapor recovery control costs were analyzed at concentrations of 100 ppmv, 1,000 ppmv, and 3,000 ppmv. Table 1 lists key economic factors in the overall cost of vapor recovery control.

**Table 1.—Economic factors assumed to project control cost for vapor recovery of methylene chloride.**

Methylene chloride recovery value	\$0.25 per lb. (excludes taxes)
Solvent-laden airstream time	(8 hours per day, 5 days per week, 50 weeks per year, 2,000 hours/year)
Steam cost	\$5.00 per 1,000 lbs. steam
Electricity cost	\$0.040 per kw-hr.
Type of adsorbent	Activated carbon
Cost of adsorbent	\$2.00 per lb.
Cost of adsorber structure	\$11.00 per lb. (steam regen. made of Hastelloy) \$3.00 per lb. (both Brayton inert regen. systems made of 316L stainless steel)
Capital depreciation period	10 years
Interest rate	10 percent
Equipment installation factor	\$20 per CFM of solvent-laden volume airflow

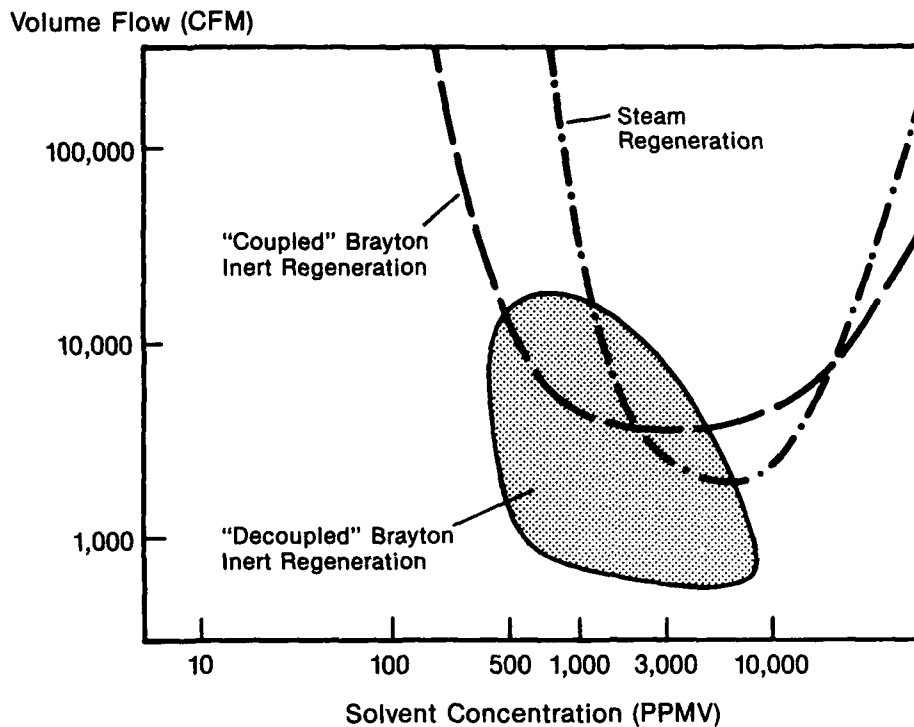
Table 2 summarizes the control cost results of the study. As you can see, concentrations above 500 ppmv are generally necessary to achieve control costs below \$5,000 per ton. Figure 4 summarizes the regions of applicability for the three vapor recovery technologies evaluated. The regions of applicability were made by assuming that control costs need to be under \$5,000 per ton of methylene chloride controlled and by comparing the relative costs of the three technologies.

**Table 2.—Control cost for paint stripping with methylene chloride (dollars per year per ton of solvent).**

FLOW (CFM)*	CONC. (PPMV)**	COSTS OF VAPOR RECOVERY CONTROL TECHNOLOGIES		
		STEAM REGENERATION	BRAYTON INERT COUPLED REGEN.	BRAYTON INERT DECOUPLED REGEN.
1,000	100	\$62,400	\$38,800	\$17,000
10,000	100	38,700	20,000	12,100
50,000	100	24,300	11,900	11,700
1,000	500	12,100	10,800	5,600
10,000	500	7,400	4,800	4,400
50,000	500	4,500	2,600	4,300
1,000	1,000	5,800	6,000	3,100
10,000	1,000	3,400	2,500	2,400
50,000	1,000	2,000	1,200	2,300
1,000	3,000	1,600	2,400	1,400
10,000	3,000	830	750	1,100
50,000	3,000	350	220	230

\*Cubic feet per minute

\*\*Parts per million by volume



\*Regions of applicability are defined by control costs at under \$5,000 per ton of solvent and the competitiveness of the technologies to each other.

Figure 4.—Regions of applicability for methylene chloride vapor recovery.

## Future Development Needs

The reduction of vapor recovery control costs will be impacted by the following critical factors and developments:

- Production of paint stripping equipment that includes solvent recovery control equipment. That is, every step must be taken to get the solvent-laden airflow down and solvent-laden air concentration up. Of course, the equipment must be designed to protect the worker from unsafe levels of solvent vapors.
- Development of a solvent recovery market infrastructure that will service many industrial users of solvents, such as the decoupled regeneration approach.
- Development of low-cost continuous solvent-laden air concentrators (that is,

rotating wheel adsorber beds) to increase the concentration of the solvent-laden air downstream of the process but upstream of the fixed bed concentrators. This will allow storage of more solvent on the fixed bed, which therefore, reduces the fixed bed cost.

- The ability to fabricate adsorbers out of low-cost materials.

## Conclusions

The recovery of methylene chloride from paint stripping applications looks promising if the concentration level of the vapor stream from the process exceeds 500 ppmv. Paint stripping equipment development should be directed at maximizing concentration levels, keeping the safety of the worker in mind.

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# MAINTENANCE PAINT STRIPPING

## Questions & Discussion

**D**iscussion in the question and answer periods of the maintenance sessions focused in large part on the details and applicability of the many substitute technologies that were presented. Following the opening session, a number of participants commented on the applicability of different blast media, including plastic media, to aircraft stripping. There was some disagreement over methylene chloride's contribution to total toxic organic air releases; Katy Wolf of the Institute for Research and Technical Assistance remarked that methylene chloride does not contribute to photochemical smog. In addition, there was discussion over whether or not carbon dioxide used in CO<sub>2</sub> blasting techniques contributed to total emissions of greenhouse gases. Mike Lewis of Cold Jet, Inc., noted that the CO<sub>2</sub> supplied for blasting is reclaimed as a regenerated waste gas and as such does not represent an additional contribution to greenhouse gas emissions. Paul Soley of Ardrex, Inc., pointed out that chemical stripping was being associated exclusively with methylene chloride. He emphasized that the chemical industry is also working on new chemistries and formulations, such as paint soft-

teners that could be an aid to mechanical stripping methods in maintenance stripping.

Following Tuesday afternoon's presentations on blast technologies, a short discussion addressed some of the mechanics of paint removal using carbon dioxide ice pellet blasting. There was some difference of opinion over the role played by thermal shock (contraction of coating due to cooling) in removing coatings from the substrate. H.C.L. Noordermeer of KLM Royal Dutch Airlines told session participants that the European airlines were also facing the problem of what process to use for coatings removal in the future. He noted that a task force of airline representatives and aircraft manufacturers was reviewing a wide variety of alternative processes and intended to formulate guidelines by which airlines could evaluate the different stripping processes being offered.

Wednesday morning's maintenance sessions included more blasting technologies as well as photo-ablative and laser paint removal systems. Discussion after the presentations raised many questions about the flashlamp/infrared and laser technologies. While heat dissipation was acknow-

ledged as a potential problem for infrared techniques on aluminum substrates, it was noted that the technique was very effective on steel structures or a thicker metal surface that acted as a heat sink. Dennis Reed of the U.S. Army asked about crack-hiding problems with blasting techniques that might smooth over or peen the surface in the process of removing paint. Questions were also raised about the potential for water in high-pressure water blasting to penetrate into airframes. Frank Scharwat responded that with the appropriate tools and controls, the process allowed adequate precision to prevent water penetration. James Swartz of Northwest Airlines raised the issue of paint stripping equipment manufacturers working hand in hand with coatings formulators to produce a system of paint/paint removal that would be effective as a coating yet still easily removed when desired.

The final session on Wednesday morning comprised presentations on paint stripping waste management and pollution prevention through vapor recovery. Discussion included questions to Gail Bowers-Irons about the particulars of the

microbial biodegradation of paint wastes. Specifically, discussion included questions about the ultimate disposition of organic and heavy metal components of the paint wastes and the effect of particle size on the effectiveness of biodegradation. John Ogden of General Motors asked what components of a system were included in a \$28 per 55-gallon drum cost estimate. This cost did not include capitalization of equipment costs for a large-scale system. With respect to solvent vapor recovery processes, James Swartz of Northwest Airlines asked whether the use of solvent recovery processes would require the operation to obtain a treatment, storage, and disposal (TSD) permit for treatment of hazardous wastes. Louis Kovach replied that if the solvent is being re-used on site, it may not be considered a waste treatment system. Willie Smith of McGean-Rohco, Inc., noted that with paint strippers for aircraft, it is unlikely that the product you get through vapor recovery will be re-useable in that state for repeated paint stripping.

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# **HOUSEHOLD & COMMERCIAL STRIPPING**

## ***Current Paint Stripping Practices***

**Chair: Sandra Eberle**  
*Directorate for Program Management and Budget*  
*U.S. Consumer Product Safety Commission*

**Chair: Glenn Simpson**  
*Directorate for Economic Analysis*  
*U.S. Consumer Product Safety Commission*

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# Current Practices and Processes for Paint Stripping in Professional Furniture Refinishing

**Tim B. Inman**  
*Minuteman, Inc.*  
*Waterloo, Wisconsin*

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## The Roll of Stripping in a Commercial Operation

The roll of stripping in a commercial service operation has changed markedly in the past decade. At the end of the 1970s and into the beginning of the 1980s, many so-called "strip shops" existed. Their function was purely utilitarian; they stripped old layers of paint and varnish from furniture brought to them by hobbyists and treasure hunters. Pieces came into the shops from the auction block, the attic, the basement, or the barn loft.

A happy convergence of events drove this "antique" hunting passion: Celebration of the Bicentennial, national turmoil, the back-to-the-earth movement, and no-budget baby-boomers setting up housekeeping and being willing to use second-hand furniture. At the same time, a chrome-and-plastic throwaway attitude in the new furniture markets created a demand for familiar and solid furnishings at reasonable prices.

Thus, initially probably 90 percent of the strip shop business was just stripping. Customers would take the cleaned pieces home and apply the stain and varnish coats themselves. As the novelty wore off, and as the appeal of the "homemade" refinishing look faded in a more affluent period, furniture stripping shops began to hear requests for more complete services.

Today, the market has changed to the point that the percentages of work have nearly reversed themselves, with almost 95 percent of the furniture entering a shop for the full treatment. Only about 5 percent is there just to be stripped clean and made ready for the customer who will do the final finishing work.

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## New Products for Stripping

Just as the mix of activity has changed during the past decade, so has the profile of the furniture items being brought into the shops for service. Earlier, solid wood items like oak chairs and tables, maple Shaker stands, and the massive, solid walnut and mahogany Victorian furniture made up the bulk of the work. Currently, interest is focused more on the delicate veneers and inlaid pieces showing the Art Deco influence of the 1920s. The smaller, more highly styled pieces are quite popular.

The condition of the objects has also changed. Where once no item was considered for refinishing if it needed much repair at all, it is now not uncommon to restore furniture that has been severely broken and damaged. Where once only solid wooden articles were refinished, now multiple materials, like leather inlays, metal and ivory boule, and exotic matched veneers are common.

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## Processes Typical in Commercial Shops

### *Types of Equipment*

Essentially two processes are used to remove undesired coats of old finish in all shops: chemical removal and mechanical removal. Nearly all professional furniture stripping operations maximize the use of chemical removal methods. Mechanical elimination of finish from furniture has not thus far proven to be both effective and nondestructive to the fine wood substrate.

Within the bounds of the chemical process, there are three common methods of applying the various solutions: (1) by hand (typically with a brush); (2) through a pumping system (typically with a hose and brush); or (3) by immersion (in vats).

It is interesting to note that it has been the delivery device—the brush, the pump, or the vat—that has received the greatest attention in the marketplace. Salespersons make extravagant claims for the type of equipment they are selling. Actually, the chemical the device delivers is the important element. Until very recently, this fact has received almost no attention. The brush doesn't strip, nor does the pump or the vat; the chemical, not the delivery device, determines the success of the process.

Efficiency dictates that commercial furniture shops use either vats or pumps to deliver stripping chemicals to the work surfaces. Pumping systems are the most commonly found among the shops by a large margin of four to one over vat systems.

Pumping systems are very inexpensive to make; a motor, a pump, a length of hose, and a brush are all that are needed to devise a functional system. Commercially assembled pumping systems are superior in design and easily shipped. Pumping systems also require almost no experience or training to be used successfully.

Immersion vat systems are also simple technology, but they are much more expensive and cumbersome to make. Costs of keeping vats charged with chemicals are higher than in any other system. Many refinements have been accomplished over the years to make commercially designed vat systems superior to home-made units, but vats are the most expensive pieces of equipment to transport. Immersion vat systems also require the most training and experience to be used to their full advantage.

### ***Types and Quantities of Chemicals***

Until the early 1970s, benzene was the solvent used to strip chemicals. It is both flammable and toxic. After its health safety risks became known, benzene was replaced as a stripper by methylene chloride products. Nonflammable, infinitely safer than benzene, and quite effective, these compounds have been used successfully ever since.

Methylene chloride, by itself, is not the best paint remover. It must be spiked with activating agents to produce the most powerful results. Acids, alkalies, amines, and phenols are used for this purpose. Wetting agents also help reduce the

surface tension and hence further improve the penetration. Thus, the explosion of different removers on today's market—each claiming to be better than the rest.

Methylene chloride is also usually the single most expensive component in the remover formulas, often by a factor of four to one. Thus, there is a tremendous incentive to make the product cheaper by adding less expensive diluent components like alcohols, toluene, xylene, acetone, simple mineral spirits, or even water. Usually this not only reduces the efficacy of the product but also, depending upon the compound used, adds health or flammability hazards—or both.

Brushing applicators and pumping system users are usually limited to solvent removers. Immersion vat operators may use water-based strippers in addition to, or in place of, solvent applications. Vat operators historically have used hot water and lye. The combination is cheap, effective, and has been recommended in furniture refinishing guides. Despite these facts, lye will, unfortunately, damage furniture. Lye will attack anything organic, including wood, glue, and veneer. Nevertheless, it continues to be used in some shops.

Far superior water-based stripping compounds have been available on the market for many years. These complex alkaline compounds effectively remove many of the older finishes that solvent removers like methylene chloride find troublesome.

### ***Quantities of Solvent Removers Used***

Most people engaged in removing solvents use pumping systems, and this process uses the largest quantity of solvent removers. Many of these operators use in excess of twelve 55-gallon drums of product each year. By its very nature, the pumping process creates the greatest surface area exposure and hence has the highest evaporation rate (and operator exposure) in the industry.

Despite the fact that pumping systems are the most common and least expensive process, they are not the most effective paint removers.

Immersion vat systems often use both water-based alkaline removers and solvents. They currently represent the smaller percentage of market share. However, vat systems are much more efficient in their use of solvent removers. While many pumping systems use in excess of twelve 55-gallon drums per year, few vat operations consume more than four to six 55-gallon drums per year, or about one-third to one-half of the consumption of a

pumping system operator. The market dilemma from the chemical supplier's point of view should be apparent.

Further, vat system operators using proper techniques and equipment are usually exposed to less remover vapors and use far less remover per item than in any other system. Because of their ability to hold the stripping chemistry in intimate contact with the finish surface without being subject to evaporation, vats are also the most effective delivery vehicles. Vat systems can offer superior performance as well as superior exposure and consumption characteristics.

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## Types of Coatings

As furniture degrades, it is abused. The professional furniture stripper encounters all types of paint and finishes including fine French polish, varnish, interior kitchen enamels, exterior house paints (lead and mozzarella), floor enamels, and marine finishes. Sometimes several finishes are removed from a single piece—for example, John Deere green implement enamel (farm tractor paint) has been found on a marble-topped Victorian walnut table.

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## Special Concerns

All of the ordinary business considerations face a commercial stripping operator: overhead, time, labor, and so forth. But a professional furniture restorer also has some special concerns that control and narrow the selection of equipment, chemistry, and techniques. Hidden below layers of paint is a substrate of unknown description. This may be veneer, solid wood, plastic, or metal. The substrate may be in good shape, or it may be ready to fall into pieces. All too often, a piece that would be considered "junk" becomes much more valuable following restoration.

Like a physician, the professional furniture restorer seeks first to do no harm. A very special concern is care of the wooden skeleton hidden beneath layer-after-layer of grafted skins of paint. It is bad practice to experiment with unknown and untested chemistry at the risk of damaging the unknown substrate.

In addition, the workplace and personal safety must also be carefully considered. It is not worth jeopardizing health and safety for the sake of salvaging an auction find. In addition to the workplace, the broader environmental issues

must also be taken into consideration with safe disposal of wastes and toxics. Handled thoughtfully, no solvent need ever be dumped. By using a properly formulated blend, solvent removers can be continually reclaimed and reused. The paint solids, consisting mostly of gums and resins, can be effectively removed and disposed of dry. It is the same paint that would have been thrown away had the whole furniture piece been discarded. Of course, as a result of the stripping, the paint is collected and concentrated. This should make handling and containment efforts much simpler. Happily, there is as much economic incentive for the commercial operator to reclaim and recycle the solvents as there is environmental rationale.

Reducing air exposure concentrations has not received the attention it deserves. Hopefully, with the passage of the Clean Air Act, this will now change. The many improperly designed, installed, or used pumping systems for stripping represent a tremendous air contamination source for both the operator and the environment. Designing better air handling systems, encouraging more use of vats and "passive" application devices, and developing better evaporation-retarding chemistry will address this problem. Unfortunately, the commercial interests of solvent suppliers mitigate against the aggressive marketing of less dangerous vats, since they can often sell two to three times as much product to pumping system operators than they can to immersion vat users.

A final issue is flammability. Because of methylene chloride's nonflammable quality, fires in commercial shops using a methylene chloride product professionally designed for the purpose have not been common for many years. Previously, when benzene was used, fires were the leading cause of injury. If today's volume of stripping was done with flammable products like acetone, lacquer thinner, benzene, or some of the newly proposed flammable methylene chloride alternatives, this risk would increase enormously.

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## Conclusion

Furniture stripping has become a very safe occupation for both the operator and the work product. More furniture is being restored and reused today than ever before. Thousands of workers are actively involved, including the handicapped in special workshops. Millions of pieces of furniture have been given a new lease on life. Exotic lumber and cabinetry have been preserved for the enjoyment of generations yet to come, and

the strain on forests to constantly produce more wood has been eased.

When accidents have occurred, there have usually been contributing factors such as intentional misuse. Equipment and workplaces can be made even safer and more accident free. Equipment design, chemistry formulation, and worker technique all need to be addressed.

Regardless of the toxicological aspects of methylene chloride, there are no products available to the industry that are as effective, safe, and fire resistant as this substance. It is hoped that, in the zeal to further reduce the very small risks associated with paint removing, more hazardous situations are not inadvertently created.

Several suggestions should be considered to improve safety and health aspects of the paint remover industry. These are:

- Follow the European lead and encourage the use of vat and more passive application systems. Minimize exposure by limiting surface area exposure. Explore alternatives but do not condemn a proven product too quickly; the alternatives may prove to be worse.
- Reduce the all-or-none rhetoric in the methylene chloride battle. A middle-ground compromise may be a much more fruitful approach to the

problem. Instead of a one-step process, a multi-tiered approach should be implemented. Methylene chloride or the alternative solvent removers can be used where they are needed and work best, as appropriate. For example, buttermilk paint strips best under contact with a water-based alkaline material.

With this approach, the newer, more solvent-susceptible layers of unwanted finish are removed by immersion in a methylene chloride stripper. Lower layers that do not respond well to this solvent should be removed with one of the alternative strippers. This system not only produces less chemical exposure, it results in a superior work product.

Care should be taken not to encourage well-meaning but unsuspecting people to buy cans of untested products that proclaim on the outside labels, "NO HARMFUL METHYLENE CHLORIDE," when in fact they contain substances that are more dangerous. Citizens, as well as policy makers, want to believe that a magic new technology can solve all problems; unfortunately, not magic, but patience and careful consideration of available options are required to reduce safety and environmental risks in the paint stripping industry.

# Do-it-yourself Paint Stripping Practices: The Household Market

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## Introduction

The do-it-yourselfer typically purchases paint strippers for relatively small jobs, such as restoring furniture or refinishing wood surfaces. Judging from estimates based on calls to Savogran's toll-free 800 information number, the majority of consumers who use paint remover—85 percent—strip furniture; the remaining 15 percent strip interior and exterior woodwork, metallic items, and masonry surfaces.

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## Typical Coatings

A number of different kinds of paint and finishes are used in and around the home. From the do-it-yourselfer's perspective, they can be divided generically into two groups: enamels and clear finishes.

### Enamels

A pigmented finish designed to produce a smooth, hard coating, enamel is easily cleaned and highly resistant to weather and wear. Enamels are available for both interior and exterior use. Commonly used binders in enamel finishes include the following resins:

- **Alkyds:** Alkyds are a group of synthetic resins that generally possess excellent drying properties combined with flexibility and durability.
- **Linseed Oil:** Linseed oil is a durable, medium-gloss resin used largely in house and trim paints. It is also an important modifying oil in synthetic alkyds.

- **Latex:** The most common latex paints, acrylic and vinyl, are sold in high-gloss, semi-gloss, or flat finishes. Latex paints are durable and weather well.
- **Epoxy:** An epoxy coating system has exceptionally good adhesion and is resistant to water and mild chemicals.

### Clear Finishes

Unlike paints, clear finishes are pigment-free and therefore do not hide surfaces. However, because they do not contain pigments, clear finishes do not stand up to sun and weather as long as enamels. The predominant clear finishes are:

- **Varnish:** A clear, solvent-thinned finish used on wood surfaces, varnish is generally resistant to moisture and wear. Spar varnish is used for exteriors and boats; catalyzed varnishes provide a protective finish on kitchen cabinets.
- **Shellac:** A clear finish made by reducing natural resins in alcohol, shellac dries rapidly and is often used as a sealer to prevent bleeding from wood or as a final finish on furniture.
- **Lacquer:** A fast-drying finish that contains nitrocellulose, lacquer is used primarily on furniture. It produces a water white finish that emphasizes the natural wood grain.
- **Polyurethane:** Polyurethane is a clear finish that is used as a protective coating on furniture, interior woodwork, and hardwood floors. It is extremely durable and can be modified with an alkyd.

## Paint Stripper Application

The do-it-yourselfer generally applies paint remover with a natural bristle brush. Coverage and number of applications depend on the type and numbers of layers of coating. For methylene chloride formulations, coverage varies from 50 to 100 square feet per gallon and time to lift the paint from 15 to 30 minutes. For non-methylene chloride formulations, coverage is generally 15 to 25 square feet per gallon and time to soften paint from 30 minutes to 30 hours. Methylene chloride removers are laid in one pass—not brushed—onto the surface by working in one direction and applying remover to about two square feet at a time. Since non-methylene chloride formulas have low evaporation rates, the stripper is laid onto the total area to be stripped.

When testing shows that the remover has done its work, the resulting sludge is removed by a gentle scraping with a dull putty knife. On carved or grooved surfaces, use an old toothbrush or coarse twine. After removing the bulk of the sludge, wipe away remaining residue with mineral spirits (or a detergent solution if using the water-wash method).

## Consumer Concerns

Consumers are increasingly more concerned about product hazards, costs, and effectiveness. Unfortunately, hazard and cost are two competing criteria. Manufacturers can stop using methylene chloride in solvent-based products, but costs, stripping times, and flammability will all increase. In addition, consumers have reacted negatively to slower-working dibasic ester (DBE) formulations. Their need for a faster-acting product seems to outweigh hazard concerns.

There is a point at which the cost of a gallon of paint remover becomes prohibitive, as exemplified by *N*-methyl pyrrolidone (NMP) formulations that have a raw material cost of approximately \$12 per gallon. A typical NMP formula has a suggested retail price of \$10.31 per 32-ounce container, which provides retailers with a 39 percent margin, while representative methylene chloride removers cost \$7.16 per 32-ounce containers, giving retailers a 55 percent margin. Consumer costs for paints are also affected by the two-step distribution system, which adds to the final retail selling price.

Remover effectiveness encompasses certain application characteristics. Manufacturers have investigated using amines as possible activators,

but many amines stain wood. Although removers should not corrode metal or raise the grain of the wood, many non-methylene chloride formulas contain water, which affects fine woods and veneers. Also, removers should not require neutralization or have an objectionable odor.

## Paint Stripping Formulations

Paint strippers can be liquid, heavy-bodied, or semi-paste, depending on the intended application. In general, liquids work best for intricate and flat horizontal surfaces. Heavy-bodied and semi-paste strippers cling, making them ideal for irregular surfaces. Removers are also water washable or solvent washable. The water-wash method works well but tends to raise wood grain and loosen glued veneers. Solvent rinses are basically problem-free.

Chemical composition also dictates formula parameters. Slower-working, low vapor pressure formulas such as the DBE must be thickened to stay on the surface and penetrate the paint film. Because they act quickly, methylene chloride formulas can be made in a variety of viscosities. The following groups of removers are based on the major active ingredient(s) in the formulas.

- **Nonflammable Methylene Chloride:** This formula generally contains greater than 75 percent methylene chloride and 5 to 15 percent methanol, ethanol, isopropanol, or a combination of the three. Some formulas use mineral spirits to reduce raw material cost. The formula is thickened with a cellulose thickener, includes paraffin wax to retard evaporation, and may also contain detergents to make it water washable and activators such as potassium oleate.

The nonflammable methylene chloride formula is the strongest and most efficient, and the only one that removes tough finishes such as catalyzed varnishes, epoxies, and baked enamels. Lastly, because of the high methylene chloride content, the products are nonflammable.

- **Flammable Methylene Chloride:** This formula generally contains 15 to 20 percent methylene chloride, 20 to 25 percent methanol, 35 to 40 percent toluene, and 20 to 25 percent acetone. Mineral spirits may be used in place of a portion of the toluene to comply with non-photochemically reactive requirements in states such as California. The formula may also include a

cellulose thickener, paraffin wax to retard evaporation, and detergents to make the composition water washable.

This formula is effective on lacquers and shellac because of the high acetone and methanol levels, and also works well for short-oil alkyds because of the high toluene level. The raw material cost is one of the lowest, comparable only to the flammable non-methylene chloride formulas, which are less efficient.

- **Flammable Non-methylene Chloride:** The formula generally contains acetone, methanol, toluene, and mineral spirits, with percentages varying between manufacturers depending on formula parameters. Acetone levels are controlled to keep the flash point acceptable, and toluene levels must be under 20 percent for products sold in California. Acetophenone, which has a strong odor, is sometimes added to improve efficiency. The formula may include a cellulose thickener (depending on application), a paraffin wax to retard evaporation, and detergents to make the composition water washable.

This formula is effective on the same type of coatings as flammable methylene chloride, but may work slower. The flash-point is generally lower than that of flammable methylene chloride.

- **Powdered Caustic Removers:** These removers generally contain sodium hydroxide, fillers, and thickening and wetting agents. Products are mixed with water to form a paste and applied in a heavy coat. This formula works slowly and is not effective on latex paints. Sodium hydroxide, which irritates eyes and skin, will darken some types of wood and may raise the grain. Caustic removers work well on old milk paints.
- **Furniture Refinishers:** Formulas currently on the market are similar to the solvent composition of flammable removers. Furniture refinishers, which never contain thickeners and may not include wetting agents, work only on clear finishes and are used in conjunction with steel wool. Some refinishers contain methylene chloride.
- **Dibasic Ester Removers:** DBE, which is a blend of dimethyl adipate, dimethyl glutarate, and dimethyl succinate, is

emulsified in water and thickened to make a paint remover. Wetting agents are also added to improve penetration through the paint film. DBE has a vapor pressure below 0.2mm Hg at 20°C, which helps keep the remover wet for extended periods. DBE removers have no objectionable odors and are considered somewhat safer than conventional removers; however, they work much slower and usually cost considerably more.

Users of DBE have reported cases of blurred vision, which are being investigated. Consumers, who are accustomed to the almost immediate result of conventional removers, must be educated to use DBE, which is applied in a heavy coat and left to work.

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## Consumers Product Safety Council Labeling Requirement

The Consumer Product Safety Council labeling requirement for products containing methylene chloride, combined with better point-of-purchase material that describes important stripping considerations such as worksite selection, setup, cleanup, safety, and health effects, appears to be having a positive effect on the way consumers use paint removers. Consumers are not deterred from buying the products, and, with this information, now use them more responsibly.

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## Recent and Future Developments

One of the most recent developments in household paint strippers has been the introduction of a new NMP formula. However, the estimated price for the NMP formula is \$50 per gallon, whereas the typical nonflammable methylene chloride remover retails for approximately \$20 per gallon.

Other solvents suggested as possible methylene chloride substitutes because of their desirable properties such as low toxicity, high flash point, and high solvent activity include:

- **Furfuryl Alcohol:** A member of the family of heterocyclic compounds known as the furans, furfuryl alcohol resinifies (converts to resin) violently in the presence of strong acids. Furfuryl alcohol has an objectionable odor.

- **Propylene Glycol Ethers:** These ethers are ineffective paint strippers. Propylene glycol monomethyl ether acetate shows some potential as a cosolvent in stripper formulations.
- **G-Butyrolactone:** This heterocyclic chemical has similar properties to NMP, including high cost.
- **Propylene Carbonate:** This chemical has been suggested as a methylene chloride substitute because of its success in the electronics industry. It is an ineffective paint stripper.
- **Trioxane:** Trioxane, which is an anhydrous cyclic trimer of formaldehyde, can sublime to produce flammable vapors. Trioxane is a crystalline solid that must be dissolved in a cosolvent. When the cosolvent evaporates from the substrate, trioxane recrystallizes. The solid has a flash point below 1.0°C.
- **Ethyl-3-Ethoxypropionate:** A linear molecule that has limited stripping abilities.
- **Dimethyl Sulfoxide:** This chemical has an extremely objectionable odor and limited stripping abilities.
- **Cyclohexanone:** A ketone with high flash point and limited solvent activity, cyclohexanone has exhibited potential as a cosolvent in stripper formulations.

- **Methyl-N-amyl Ketone:** This chemical has a strong odor and limited solvency.

- **Alkyl Acetates:** These chemicals have a strong odor and limited solvency.

These compounds have been investigated in different combinations and with many types of possible activators. No synergism equals the performance of methylene chloride. The parameters under which stripper formulation testing is performed are important. Certain stripper formulation data can be misleading; for example, data can vary with the length of time paint panels are dried. Formulating a cost-efficient formula is difficult, because the raw material cost for these compounds is three to eight times more than the raw material cost of methylene chloride.

Future developments should include products that exhibit low toxicity, biodegradability, non-photochemical reactivity, low volatile organic content, efficient paint removal, and flash points above 100°F. Savogran has developed products that meet all these criteria with the exception of efficient paint removal at room temperature. However, to match the efficiency of methylene chloride formulations, the product must be heated, which is unacceptable for the consumer market but tolerable for most industrial applications. (The high cost also makes these products much more acceptable for the industrial market.) While many efficient paint stripping products are available, technology has not progressed to the point where manufacturers can produce a cost-effective formula that meets the consumer's expectations.

# Comparative Performance of Substitute Paint Stripper Formulations

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**C**hemical suppliers are continually challenged to develop safer, more cost-effective chemicals for any given application, including paint strippers for household and commercial furniture refinishing. Methylene chloride is presently the primary solvent used in chemical stripping formulations. Concerns about potential health effects associated with using methylene chloride have, over the past few years, led to a renewed search for alternative solvents. This paper describes a test procedure that Dow Chemical has used to screen paint stripper formulations and the results of those tests. It also provides additional perspectives on issues that must be considered as industry works to develop new paint-stripping formulations.

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## Background

The ideal paint stripper would have three major characteristics: good performance, a good safety and health profile, and low cost. However, in reality the choice among existing products requires considering a series of trade-offs to gain the greatest total benefit for the job at hand. The next generation of paint stripping formulations must meet new needs; to accomplish this goal, it is necessary to understand how the formulations currently used were developed.

The development of today's highly efficient paint strippers has a long history, dating to the early twentieth century when Carlton Ellis and Boris Lougovoy patented numerous formulations. Ellis is further credited with developing nonflammable strippers to replace such solvents as benzene, toluene, acetone, and ethanol, which were commonly used at that time. Kuentzel and Liger

reported their evaluation of the relative stripping power of numerous chlorinated solvents in 1947. Berkeley, Schoenholz, and Sheehy expanded upon this list in 1955. Concurrently, the introduction of more chemically resistant coatings made the search for solvents that would work effectively more difficult. It was through the research efforts of these and many other people that the wide use of methylene chloride as the primary component of paint strippers for both industrial and household applications evolved.

Methylene chloride based-furniture strippers currently used generally consist of the components listed below. While exact formulations vary, each component has a specific function:

- **Methylene chloride:** This is the active ingredient that penetrates the coating. Because of its relatively high evaporation rate, once through the coating, the vapor pressure generates blisters and lifts the film from the substrate.
- **Paraffin wax:** This wax retards evaporation, forming film on the surface. It contains the toxic substance toluene as a solvent for the wax.
- **Cellulosic thickener:** The thickener holds paint stripper on vertical surfaces. While a thickener is often used in formulations for consumer use, it may or may not be used in commercial strip shop formulations.
- **Methanol:** This is the active ingredient, as well as solvent, for the thickener.
- **Mineral spirits:** The spirits keep the paint film wet.

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## Defining Performance

There are several criteria that define good performance. A paint stripper must work on a number of different surfaces, to remove a variety of different coatings. Particularly when refinishing old furniture, several layers of different kinds of coatings may have to be removed, adding another level of complexity.

Speed and ease of removing the coating are also important to the end user. For example, an extremely good solvent for the coating may not provide the most desirable remover if the solubilized coating redeposits on the substrate, making additional treatments necessary. From a strip shop operator's standpoint, this could also be undesirable, because the formulation would rapidly become contaminated, decreasing the number of pieces that could be stripped with a given volume of formulation. Finally, the formulation (or the technique) must not harm the substrate, and must not adversely affect the ability to recoat.

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## Experimental

The purpose of this study was to establish a laboratory method for screening the performance of paint stripper formulations in a uniform, measurable manner.

Thirty-nine paint stripper formulations were tested for this purpose. These formulations consisted of commercially available products, as well as formulations prepared in the laboratory from literature references. The formulations are defined as completely as possible in Tables 1-4, although specific product names have been deleted. For ease of reference, the formulations have been grouped in categories according to components used in the formulations. "Traditional formulations" are those containing methylene chloride and/or other standard solvents such as aromatic hydrocarbons, alcohols, and ketones. "NMP Formulations" are those containing standard solvents blended with *N*-methyl pyrrolidone. "Ether/Ester Formulations" contain those materials blended with standard solvents, and the "NMP/Ether/Ester Formulations" represent mixtures of all the above materials.

Boards of oak, maple, and pine were chosen as representative of open/closed grain hard/soft wood substrates. The boards were sanded and cleaned with a tack cloth. Each board was divided into five equal sections using masking tape. Two coats of a representative coating were then applied

to the unique sections of the board, allowing two days cure time followed by light sanding and cleaning with a tack cloth between coats. The five coatings used were the following: an alkyd enamel, latex semigloss enamel, flat acrylic latex, spar varnish, and urethane varnish. Both sides of each board were prepared in the same manner.

One side of the board was stripped two weeks after coating, the other six weeks after coating. All coatings were more difficult to remove after six weeks. Further, early tests indicated oak to be the more difficult substrate. Therefore, only strippers that performed acceptably on the maple and pine screening were tested on oak. Polyurethane varnish was the most difficult coating to remove. Again, only those formulations that showed good performance on the first four coatings were actually tested on the polyurethane varnish.

The stripping tests were conducted as follows: Prepared and cured boards were divided into one-inch segments, again using tape. Five drops of stripper were applied per square inch. An even scrape was applied using a .25-inch spatula on the surface every 10 seconds until bare wood was observed. The time taken to strip the coating (observe bare wood) was then recorded. With the exception of trying to remove urethane varnish, an individual test was suspended after five minutes if the coating could not be removed.

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## Results and Conclusions

The data from the tests performed after a six-week cure are shown in Tables 5-8. Figures 1 and 2 summarize the data for all formulations in order of observed performance for all coatings except polyurethane varnish. The performance data on polyurethane varnish are summarized separately in Figure 3.

As a group, the traditional formulations outperformed all other groups of formulations in this screening test. A second tier of performance, those formulations taking an average of approximately 1.5 minutes to strip most coatings, was observed. Performance of this group appeared to depend more on the concentration of solvents such as toluene and xylene in the formulation than the choice of alternative solvents. The poorest performers were those formulations that not only did not include methylene chloride, but also did not include toluene or xylene.

A similar trend for the traditional formulations can also be seen for relative performance on polyurethane varnish. It is interesting to note that formulation number 7, which contains a high

Table 1.—Traditional formulations for paint strippers.

COMPONENT % BY WEIGHT	FORMULATION NUMBER							
	1	2	3	4	5	6	7	8
Acetone			20		19.7	22.2		13.1
Acetophenone							55	
Alkyl acetates								
Amines								13.4
Aromatic blend								
Cellulosic	1.2			1.5			1.5	
Dibasic esters								
Diethylene glycol n-butyl ether								
Ethanol								
Ethyl-3-ethoxy-propionate								
Ethylene glycol n-butyl ether								
Isopropanol								
Methanol	7.8	15		19	26.6	22.2	19	43.9
Methyl amyl ketone								
Methyl ethyl ketone								
Methylene chloride	81.1	70	60	55	38	22		
Mineral spirits	6.2							
Mixed glycol ethers								
n-Butanol								
N-methyl-2-pyrrolidone								
Propylene carbonate								
Propylene glycol methyl ether								
Propylene glycol methyl ether acetate								
Toluene	2.1	15	20	23.5	15.1	26.1	23.5	27.9
Unidentified					0.6	6.4		1.7
Wax	1.6			1.5			1.5	
Xylenes								

Table 2.—N-methyl pyrrolidone formulations for paint strippers.

COMPONENT % BY WEIGHT	FORMULATION NUMBER							
	9	10	11	12	13	14	15	16
Acetone								
Acetophenone								
Alkyl acetates								
Amines							10	10
Aromatic blend							45	45
Cellulosic	1.5							
Dibasic esters								
Diethylene glycol n-butyl ether								
Ethanol			20		40			
Ethyl-3-ethoxy-propionate								
Ethylene glycol n-butyl ether								
Isopropanol								
Methanol	19							
Methyl amyl ketone								
Methyl ethyl ketone				20		40		
Methylene chloride								
Mineral spirits								
Mixed glycol ethers								
n-Butanol								
N-methyl-2-pyrrolidone	55	50	40	40	30	30	45	45
Propylene carbonate								
Propylene glycol methyl ether								
Propylene glycol methyl ether acetate								
Toluene	23.5							
Unidentified								
Wax	1.5							
Xylenes		50	40	40	30	30		

**Table 3.—Ether/Ester formulations for paint strippers.**

COMPONENT % BY WEIGHT	FORMULATION NUMBER											
	17	18	19	20	21	22	23	24	25	26	27	28
Acetone		20		42	42	33						
Acetophenone										27.5		
Alkyl acetates		30	25	25	25	33						
Amines												
Aromatic blend												
Cellulosic	1.5							2	1.5	1.5	1.5	
Dibasic esters												35
Diethylene glycol n-butyl ether												
Ethanol												
Ethyl-3-ethoxy-propionate							50	48				
Ethylene glycol n-butyl ether												
Isopropanol			18	18								
Methanol	19								19	19	19	
Methyl amyl ketone							30	40				
Methyl ethyl ketone		20	42									
Methylene chloride												
Mineral spirits												
Mixed glycol ethers												
n-Butanol		10			18		20	10				
N-methyl-2-pyrrolidone												
Propylene carbonate											55	
Propylene glycol methyl ether									55	27.5		65
Propylene glycol methyl ether acetate												
Toluene	23.5	20	15	15	15	34			23.5	23.5	23.5	
Unidentified												
Wax	1.5								1.5	1.5	1.5	
Xylenes												

**Table 4.—NMP/Ether/Ester formulations for paint strippers.**

COMPONENT % BY WEIGHT	FORMULATION NUMBER										
	29	30	31	32	33	34	35	36	37	38	39
Acetone											
Acetophenone											
Alkyl acetates											
Amines											
Aromatic blend											
Cellulosic	1.5										
Dibasic esters											
Diethylene glycol n-butyl ether		20		40							9.9
Ethanol											
Ethyl-3-ethoxy-propionate								21.8	27.2	22.9	
Ethylene glycol n-butyl ether								22.7	22.4	23	
Isopropanol											
Methanol	19										
Methyl amyl ketone											
Methyl ethyl ketone											
Methylene chloride											
Mineral spirits											
Mixed glycol ethers											31.9
n-Butanol											
N-methyl-2-pyrrolidone	27.5	40	40	30	30	40	30	28.7	21.3	28.2	17.9
Propylene carbonate											
Propylene glycol methyl ether	27.5		20		40						
Propylene glycol methyl ether acetate						20	40				40.3
Toluene	23.5										
Unidentified								26.8	29.1	25.9	
Wax	1.5										
Xylenes		40	40	30	30	40	30				

Table 5.—Performance of traditional formulations (after a six week cure).

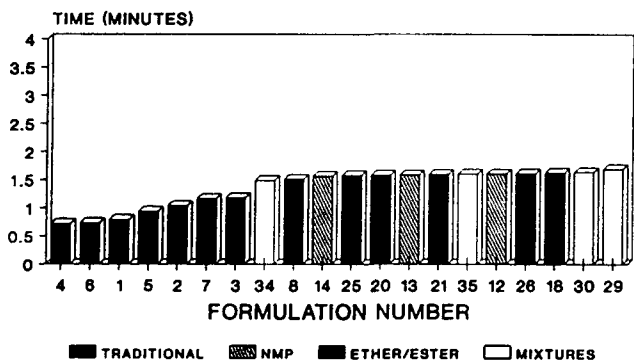
FORMULATION NUMBER	TIME TO REMOVE COATINGS (MINUTES)				
	ALKYD ENAMEL	FLAT ACRYLIC LATEX	LATEX SEMI-GLOSS	SPAR VARNISH	POLY-URETHANE
<b>MAPLE SUBSTRATE</b>					
1	1.17	0.67	0.5	1.17	0.83
2	1.5	0.67	0.5	1.5	2.33
3	1.83	0.83	0.5	1.17	2.33
4	1.0	0.5	0.5	0.83	2.17
5	1.17	0.5	0.33	1.0	1.83
6	1.0	0.5	0.33	0.83	1.83
7	1.17	0.83	0.67	1.67	6.33
8	2.0	1.17	0.5	1.5	2.5
<b>PINE SUBSTRATE</b>					
1	1.0	0.67	0.5	0.67	1.5
2	1.33	0.67	0.5	1.17	3.83
3	2.17	0.83	0.5	1.17	3.83
4	1.17	0.5	0.5	0.83	0.83
5	1.33	0.83	0.5	1.5	2.17
6	1	0.5	0.5	0.67	2.5
7	1.5	0.67	0.67	1.67	6.5
8	1.5	1.33	0.83	2.33	
<b>OAK SUBSTRATE</b>					
1	0.83	0.5	0.33	1.5	1.83
2	1.33	0.67	0.5	2.17	5
3	2	0.67	0.5	2	4.17
4	1	0.5	0.33	1	1.83
5	1.33	0.67	0.5	1.67	2.17
6	1.17	0.5	0.33	1.5	2.67
7	2	0.67	0.67	1.83	7.33
8	1.5	1		3	3.5

Table 6.—Performance of N-Methyl Pyrrolidone formulations (after a six week cure).

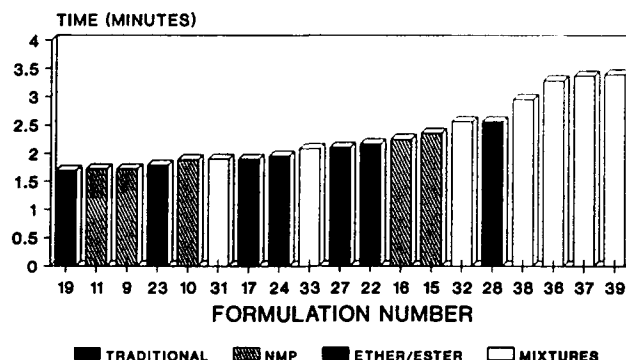
FORMULATION NUMBER	TIME TO REMOVE COATINGS (MINUTES)				
	ALKYD ENAMEL	FLAT ACRYLIC LATEX	LATEX SEMI-GLOSS	SPAR VARNISH	POLY-URETHANE
<b>MAPLE SUBSTRATE</b>					
9	1.83	1.5	0.67	2.67	
10	2.67	1.17	0.83	2.83	3.83
11	2.17	1.17	0.83	2.83	4.33
12	2.33	1.17	0.5	2.33	3
13	2.33	1.17	0.67	1.83	3.5
14	1.83	0.83	0.67	2	3.33
15	3.5	1.67	1	3.17	
16	3	1.5	1	2.5	
<b>PINE SUBSTRATE</b>					
9	2	0.83	0.67	2.5	
10	2	1.33	0.67	1.83	4
11	2	1.33	0.83	2.17	4.5
12	2	1	0.83	1.83	3.67
13	1.67	1.33	1	1.83	3.83
14	1.67	0.83	0.67	3.5	3.83
15	3.17	1.33	0.83	4.17	
16	2.33	1.5	1.17	5	
<b>OAK SUBSTRATE</b>					
9	2.5	0.83	0.67	4	
10	2.33	1.17	0.83	5	4.33
11	2	1	0.83	3.5	4.83
12	1.83	0.83	0.83	3.83	4
13	2	0.83	0.67	3.83	4.33
14	2.17	0.67	0.5	3.5	3.83
15					
16					

**Table 7.—Performance of Ester/Ether formulations (after a six week cure).**

FORMULATION NUMBER	TIME TO REMOVE COATINGS (MINUTES)				
	ALKYD ENAMEL	FLAT ACRYLIC LATEX	LATEX SEMI-GLOSS	SPAR VARNISH	POLY-URETHANE
<b>MAPLE SUBSTRATE</b>					
17	2.5	1.17	0.83	1.83	
18	2.17	0.83	0.67	1.67	6.17
19	1.5	1	0.67	2.17	9.5
20	1.67	0.83	0.5	1.5	12.83
21	4	1	0.67	2.17	
22	5	1.17	0.67	2.17	
23	2.67	1	0.67	1.83	
24	3.33	1.17	0.67	2.33	
25	2.17	1.33	0.67	1.83	7.67
26	1	1	0.83	2.17	7.3
27	2	1.5	0.83	5	
28	2.83	2.17	1	3.67	5.67
<b>PINE SUBSTRATE</b>					
17	3.5	0.83	0.83	3.67	
18	1.67	0.83	0.83	1.5	7
19	2	1.33	0.67	1.83	9.83
20	2.17	0.83	0.67	1.5	13.17
21	1.67	1.17	0.83	1.33	
22	4	1	0.67	2.67	
23	2.67	1	1.83	2.67	2.83
24	3.83	1.5	0.83	2	
25	3.33	1	0.83	1.67	5.33
26	2	1	0.67	2.17	7.83
27	3	1.67	0.83	2	
28	3.17	2.83	1.17	3.67	10.5
<b>OAK SUBSTRATE</b>					
17	3.17	0.83	0.67	3	
18	2.5	1.17	0.67	5	7.17
19	3.17	1.17	0.67	4.17	10.17
20	3	1	0.67	4.67	
21	1.5	0.83	0.67	3.33	14.67
22					
23					
24					
25	1.67	1	0.67	2.83	7.17
26	2.67	1	0.67	4.17	8.17
27					
28					



**Figure 1.—Stripping performance on all woods and finishes except urethane.**



**Figure 2.—Stripping performance on all woods and finishes except urethane.**

Table 8.—Performance of NMP/Ester/Ether formulations (after a six week cure).

FORMULATION NUMBER	TIME TO REMOVE COATINGS (MINUTES)				
	ALKYD ENAMEL	FLAT ACRYLIC LATEX	LATEX SEMI-GLOSS	SPAR VARNISH	POLY-URETHANE
<b>MAPLE SUBSTRATE</b>					
29	1.17	1	0.67	3	6.33
30	3	1.17	0.67	2.17	
31	1.83	0.83	0.67	2.83	
32	4.5	1.5	1	3.83	
33	3.17	1.17	0.67	2.83	
34	2	1	0.5	1.5	4.67
35	2	0.83	0.67	2.67	
36	4.33	3.17	1.17	5	
37	5	2.5	1	5	
38	3.83	2.5	1	5	
39	4.33	2.33	2.67	3.83	
<b>PINE SUBSTRATE</b>					
29	1.33	1	0.83	2.17	
30	2	1	1	2.1	
31	1.67	1.5	0.83	3	
32	2.83	1.67	1	4.17	
33	1.5	1	0.83	4.83	
34	1.67	1.17	0.83	2	4.67
35	1.33	1.17	1	3.17	
36	3.33	2.5	1.83	5	
37	3.67	2.83	2	5	
38	2.17	2.83	1.33	5	
39	4.67	3.5	1.67	4.17	
<b>OAK SUBSTRATE</b>					
29	2.83	1.17	0.67	4.5	7.33
30					
31	2.5	1.17	1	5	
32					
33	2	1.17	1	4.83	
34	1.5	1	0.67	4	4.67
35					
36					
37					
38					
39					

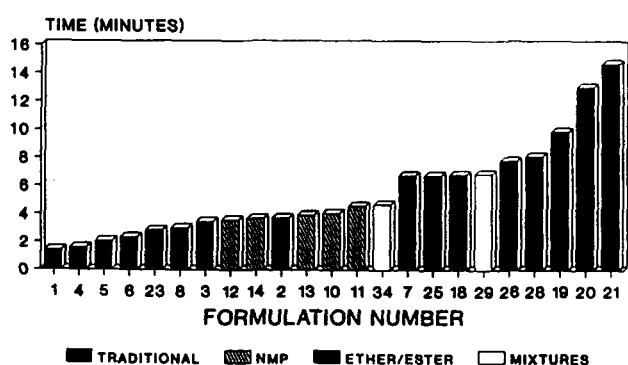


Figure 3.—Stripping performance on urethane varnish.

percentage of acetophenone, was not particularly effective on this coating. With the exception of formulation number 23, a group of NMP formulations stands out as the next best performance on polyurethanes. While there are slight differences in rank order, these same formulations also appeared within the second tier grouping on the other coatings. In general, the ether/ester for-

mulations appeared to be the poorer performers on polyurethane.

Overall, formulations 1, 4, 5, and 6 consistently out-performed all other formulations on all surfaces and coatings tested. It is important to note that the concentration of methylene chloride in these formulations ranges from 22 to 81 percent. These data would tend to indicate that at least from a strict performance standpoint, it is possible to take advantage of the desirable properties of methylene chloride without necessarily resulting in a formulation that is predominately based on this material.

## Comments and Recommendations

It is important to remember that the data presented were generated for laboratory screening purposes only. From a practical application

standpoint, the experiment did not attempt to directly translate the time to strip a test panel section to that required to actually strip a piece of furniture. Also, there is no direct indicator of the relative increase in difficulty associated with stripping coatings that have cured for years versus a few weeks; the test only shows that even a relatively short cure time does indeed increase the difficulty. Attempting to strip multiple layers of multiple types of coatings would add yet another degree of complexity to the overall equation. Thus, while the data are useful in determining general trends in performance, it would be erroneous to assume that the addition of practical end-use difficulties would necessarily result in a simple, proportional increase in time. Last, no attempt was made to assess any potential differences in recoatability or preparation time required to recoat.

The laboratory test concentrated on some of the measurable aspects of performance. As men-

tioned previously, other considerations are equally important in defining the "ideal" paint stripper, including safety and toxicity, as well as cost, waste disposal, and other environmental aspects. It is widely accepted that the methylene chloride formulations currently in use were developed in response to the needs for reduced flammability and performance on a wide variety of coatings. These same formulations are now being scrutinized because of concerns about toxicity. To develop better paint strippers, all these considerations must be evaluated in concert, including appropriate attention to relative risk. Conversely, focusing on only one consideration will most likely result in simply trading one problem for another at some future time.

**ACKNOWLEDGEMENT:** The experiments and data presented in this paper were generated by R. T. Robinette, III, and J. E. Cuzic, Dow Chemical Company.

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# **HOUSEHOLD & COMMERCIAL STRIPPING**

## ***Substitute Solvent & Non-solvent Alternatives***

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# DBE-based Stripper Formulations

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## Introduction

Du Pont dibasic esters are refined dimethyl esters of adipic, glutaric, and succinic acids. Dibasic esters are manufactured from a mixed acid coproduct stream obtained from Du Pont's three adipic acid plants. The primary refined ester product is designated DBE. Du Pont fractionates DBE to provide other mixtures and pure components to satisfy market demands (see Fig. 1).

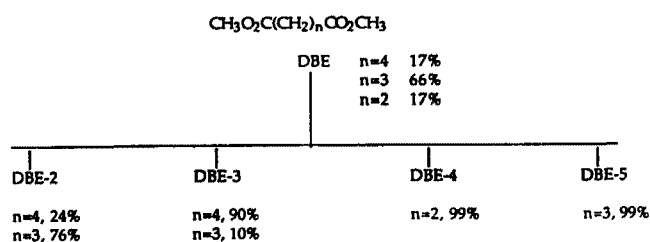


Figure 1.—Dibasic esters.

The DBEs are stable, low-cost liquids with high boiling and flash points and low toxicity; they possess excellent solvent properties. DBE itself has become one of the leading high-boiling oxygenated solvents used in the paint industry.

As indicated by their solubility parameters, DBE, DBE-2, and DBE-3 are similarly good solvents for many of the resins used in paints and other coatings (see Table 1). Because of their solvency and excellent overall balance of properties,

the DBEs and their blends with other solvents are being used to replace methylene chloride in several areas, including paint cleanup and paint strippers.

## Stripper Formulations

The DBEs can be used alone for stripping a number of paints; however, like methylene chloride and *N*-methyl pyrrolidone (NMP), they perform best when formulated with other selected solvents. Du Pont's interest is in selling the DBE solvents—not in manufacturing paint strippers. Development and evaluation of paint stripper formulations were undertaken to provide guidance to customers interested in paint stripper manufacture. These formulations have been presented to the industry as starting points that hopefully can be improved by those in the paint stripping industry.

For stripping a wide range of paints, a base blend of 70 to 80 percent DBE and 20 to 30 percent NMP is recommended (see Table 2). Experience has shown such blends to be more effective than either solvent by itself. Further, such blends are cost effective, since DBE (a relatively low-cost solvent) is the principal component, while the high-cost NMP is minimized. The preferred dibasic esters in these blends are DBE-2 or DBE-3 because of their very low vapor pressure.

Table 1.—Dibasic esters properties.

	DBE	DBE-2	DBE-3
Molecular weight (av.)	159	163	173
Distillation range, °C (°F)	196–225 (385–437)	210–225 (394–437)	215–225 (419–437)
Vapor pressure, 20°C (Torr)	0.1	0.1	<0.1
Flash point, TCC, °F	212	219	220
Solubility in H <sub>2</sub> O, wt. %, 20°C	3.1	2.9	2.5
Solubility parameters (Hansen)			
Nonpolar	8.3	8.3	8.3
Polar	2.3	2.2	2.1
Hydrogen bonding	4.8	4.7	4.5

Table 2.—Paint strippers.

COMPONENT	FORMULATIONS (WT. %)	
	A	B
Du Pont DBE-2	40	47
N-Methyl-2-pyrrolidone	15	18
Aromatic 150 <sup>1</sup>	40	—
Conosol <sup>®</sup> C-200 <sup>2</sup>	—	31
Potassium oleate (50% in H <sub>2</sub> O)	4	3
Methocel <sup>®</sup> 311 <sup>3</sup>	0.8–1.0	0.8–1.0
Flash point, TCC, °F	164	187
Cost (approximate), \$/gal <sup>4</sup>	5.50	6.00

<sup>1</sup>Product of Exxon Chemical Co.<sup>2</sup>Product of Conoco.<sup>3</sup>Product of Dow Chemical Co.<sup>4</sup>Materials costs based on "list" prices.

These formulations were developed with the objective that they would be used primarily in the original equipment manufacturing (OEM) sector. However, in addition to testing for OEM needs, the formulations were tested on wood coatings to cover a wide variety of paints and finishes. The excellent performance on the wood coatings generated much interest in DBE-based strippers for wood coatings.

## Performance

Stripping performance of DBE-based formulations versus methylene chloride-based formulations was measured on painted wood panels prepared according to Iobst et al. 1983. Eight paint types (Table 3), including five pigmented and three clear coatings, were tested over #2 pine kiln-dried boards (nominally 1" x 6" x 10'). Three coats were applied with a one-day interval between coats. For the pigmented paints, each coat was tinted a different color. After drying in air for five days, the boards were dried at 120°F for two weeks in a ventilated oven. All coated panels were stored under ambient conditions for at least 60 days before use.

Table 3.—Paint and varnish materials.

SYSTEM #	TYPE	SOLVENT OR WATER BASE	COMMERCIAL INFORMATION
1	Latex exterior enamel	Water	Top Coat(s): Muralo Latex High Gloss Enamel Prime Coat: Bruning 1210 Undercoat
2	Alkyd enamel exterior	Solvent	Top Coat(s): Bruning House & Trim Prime Coat: Bruning 1210 Undercoat
3	Lacquer	Solvent	Top Coat(s): Parks Gloss Lacquer Prime Coat: same as top coat
4	Vinyl acrylic interior	Water	Top Coat(s): Muralo SemiGloss Vinyl Acrylic Latex Prime Coat: Bruning 1210 Undercoat
5	Epoxy	Solvent	Top Coat(s): Bruning Chemical Resistant Modified Epoxy Coating #688 White Base Prime Coat: Bruning 1210 Undercoat
6	Polyurethane varnish	Solvent	Top Coat(s): McCloskey Gloss Polyurethane Prime Coat: same as top coat
7	Marine paint	Solvent	Top Coat(s): Pettit Easyepoxy High Gloss Marine Finish Prime Coat: Pettit Specialty Fiberglass Undercoat
8	Marine varnish	Solvent	Top Coat(s): McCloskey Man-O-War Gloss Spar Prime Coat: same as top coat

The methylene chloride-based strippers used were the following commercial products:

- Formby's Paint Remover, Superior Wood Formula (Formby's, Inc., Olive Branch, MS 38654). According to the label, the stripper contains methylene chloride and methanol (<4 percent).
- Zip-Strip<sup>®</sup> Paint-Varnish and Stain Remover (Star Bronze Co., Alliance, OH 44601). According to the label, it contains methylene chloride, mineral spirits, and methanol (<4 percent).

## Stripper Application and Removal

All stripper application and removal tests were conducted at approximately 75°F. The stripper was applied in heavy coat using a brush. The area covered by the coating was approximately 2.75" x 4.0" or 11.0 square inches. For the DBE-based strippers, 2 to 4 g of stripper were used to cover the 11-square-inch area. For the methylene chloride-based strippers, 5 to 7 g of stripper were used.

The DBE-based strippers were allowed to remain in contact with the painted surface for 30 minutes. At the end of this time, no losses in weight of the strippers were noted. The methylene chloride strippers, each containing a wax to slow evaporation, were allowed to contact the painted surface for 20 minutes. At the end of this time, no losses in weight of the strippers were noted.

The stripper-treated coatings were removed with a putty knife having a 1.5" blade. Whereas the methylene chloride-based strippers swelled and lifted the coatings in a somewhat bubble-like fashion, the DBE-based strippers generally softened the coating with minor lifting and bubble-like action. The softening action of the DBE-based

coatings generally extended deep into the coating, allowing ready removal when scraped with the putty knife or wiped with a cloth.

### Stripper Evaluation

Following stripper application and removal, the effectiveness of each stripper's performance on each coating type was evaluated visually. Since, in the case of the paints, each of the three coats was tinted differently, the amount of each coat was rather easily judged. For the clear coatings, it was assumed that most unremoved coating was from the first coat that had been applied.

Results of the evaluation are tabulated in Table 4. Plate I is a photo of the stripped test panels. The results show that paint and varnish removal by the DBE-based strippers is generally as effective as with commercial methylene chloride-based strippers. However, removal by the DBE-based strippers is slower by a factor of 1.5. Because of the very low vapor pressure of the ingredients of the DBE-based strippers, they can be left on the paint for extended periods without loss of the solvents, thereby providing more flexibility in working time.

### Waste Management and Cost

The solvent components of the stripper formulations discussed can be recovered for reuse by distillation under vacuum. Handling of the solid

wastes, mainly paint components, depends on their nature and composition. In industrial usage, such as auto paint booth cleanup, solvent recovery and reuse are feasible. For small stripping jobs, such as the household, waste handling procedures, like those recommended in the *Klean-Strip Guide to Paint & Varnish Removal*, should be considered.

As noted previously, materials' cost of the DBE-based strippers described are in the range of \$5.50-6.00/gal. or \$0.61-0.71/lb. Since 2 grams of stripper will strip 11 inches, the stripper materials' cost is \$0.04 for 1 square foot. Du Pont has no data on other costs involved in the stripping process and therefore cannot make a complete cost estimate.

### Handling and Safety

DBE dibasic esters are of low toxicity and have such a low vapor pressure that airborne concentrations are extremely small. However, as with all organic solvents, the DBEs should be handled with good ventilation to minimize exposure.

There have been reports of blurred vision associated with the use of paint strippers containing DBE. In all cases, the effect was noted when the DBE was misused, i.e., used with inadequate ventilation and violations of Du Pont's recommended exposure guidelines. There have been no reports of blurred vision associated with the use of DBE-2 or DBE-3.

Table 4.—Stripper performance.

COATING TYPE	DBE STRIPPERS (30 MINUTES)						METHYLENE CHLORIDE STRIPPERS (20 MINUTES)					
	FORMULATION A % REMOVAL			FORMULATION B % REMOVAL			FORMBY'S % REMOVAL			ZIP-STRIP® % REMOVAL		
	COAT 1	COAT 2	COAT 3	COAT 1	COAT 2	COAT 3	COAT 1	COAT 2	COAT 3	COAT 1	COAT 2	COAT 3
1. Acrylic latex Exterior enamel Alkyd primer	100	100	100	100	100	100	100	95	60	100	90	60
2. Alkyd exterior enamel Alkyd primer	100	95	90	100	95	95	100	90	60	100	85	60
3. Nitrocellulose lacquer	100	100	100	100	100	100	100	100	100	100	100	100
4. Vinyl acrylic interior Latex Alkyd primer	100	100	>95	100	98	90	100	90	60	100	85	60
5. Epoxy Alkyd primer	100	100	80	100	95	20	100	50	20	100	95	30
6. Polyurethane varnish	100	100	100	100	100	100	100	100	100	100	100	100
7. Epoxy marine paint Specialty undercoat	100	75	20	100	30	0	100	60	10	100	50	10
8. Alkyd marine varnish	100	100	100	100	95-100	95	100	90-100	65	100	90-100	90

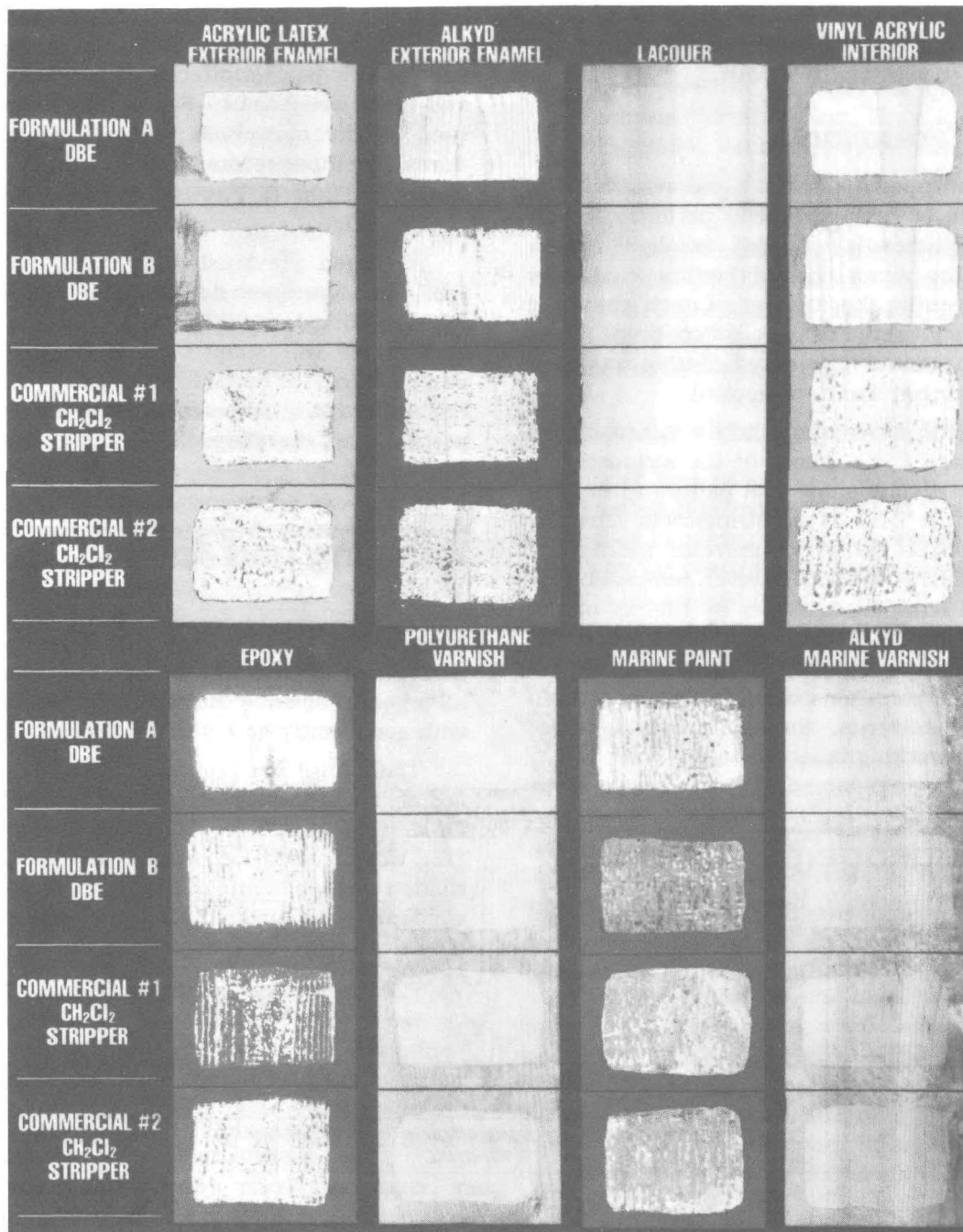


Plate 1.—DBE solvent paint stripping results.

Good practice also requires that, as with all organic solvents, skin contact should be minimized. Animal tests indicate DBE is a mild skin irritant, but is not a skin sensitizer.

## Conclusions

Du Pont dibasic ester solvents, particularly DBE-2 and DBE-3, can be formulated to effective paint strippers having low toxicity, low VOC, and moderate cost. Although slightly slower in their

stripping action, strippers containing a 75/25 mixture of DBE and *N*-methyl pyrrolidone remove most paints and varnishes as effectively as commercial methylene chloride-containing strippers.

## References

- J. Iobst, D. Sellers, R.G. Flowers, and S. Ebbert. 1983. Paint Removers. Rodale Product Test. Rep., Product Test. Dep. Rodale Press, Emmaus, PA.
- Guide to Paint & Varnish Removal*. "Klean-Strip" Marketing Dept., P.O. Box 1879, Memphis TN 38101.

# Surface Tension Modification of NMP-based Paint Strippers

William C. Walsh

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## Introduction

The solvents traditionally used in paint strippers include methylene chloride, methanol, acetone, and methyl ethyl ketone. In evaluating stripping speed, these products have some common properties that play a key role in their ability to remove paint quickly (Table 1).

Table 1.—Solvent property data.

	VAPOR PRESSURE (MM HG)	SURFACE TENSION (DYNES/CM)	REFERENCE TEMPERATURE (°C)
Methylene Cl	340	26.5	20/20
Methanol	100	22.6	21/20
Acetone	185	22.3	20/20
MEK	70	24.6	20/20
NMP	0.24	42.0	20/24

- All of these solvents consist of small, non-complex molecules. This allows fast and efficient solvent penetration of the cured paint or coating.
- They all have high vapor pressures resulting in fast evaporation rates. The quick evaporation of solvent aids in lifting paint from the substrate.
- They also have low surface tensions. This allows them to quickly "wet out" all surfaces, fill any surface pores, and begin immediate penetration of the paint film.

In combination, these properties result in paint stripping formulas that can remove most common paints and coatings quickly and effectively. *N*-methyl pyrrolidone (NMP), in comparison, has relatively different properties of molecular size, vapor pressure, and surface tension that result in slower stripping times.

- NMP is a larger molecule. As such, NMP simply requires more time to penetrate a given coating.
- NMP has a lower vapor pressure. After penetration of the coating, highly volatile solvents will lift as they flash back through the paint film. The low volatility of NMP slows this lifting process.
- NMP has a higher surface tension. The surface tension of NMP is nearly double that of other paint stripper solvents.

If any of these key properties could be modified, perhaps the stripping speed of NMP could be improved as well. Molecular size is fixed, and although vapor pressures and surface tensions can be reduced through increasing temperature, this is not a common practice in most paint stripping applications. However, through the addition of an appropriate surfactant, the surface tension of NMP blends can be modified to improve stripping speed.

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## Product Description

### Composition

Five NMP-based formulas were reviewed in this study to determine their effectiveness as paint strippers. The compositions of these five blends with their respective flash points are listed in Table 2. (Note: Flash points were determined by ASTM method D-56, Tag Closed Cup.)

For safety considerations, cosolvents were chosen so that low volatility and high flash point would be maintained in the final blend. As required, cellulosic thickeners were added to increase viscosity. Further information on the

**Table 2.—Paint stripper formulas.**

	#1	#2	#3	#4	#5
NMP <sup>1*</sup>	31.0%	60.0%	80.0%	12.0%	50.0%
Hisol® 15 <sup>2</sup>	50.0%				
EEP <sup>3</sup>	17.9%	13.9%		6.7%	
DBE <sup>4</sup>		25.0%	12.0%	80.0%	36.0%
Dowanol® TPM <sup>5</sup>			7.0%		13.0%
Methocel® 311 <sup>6</sup>	1.1%	1.1%	1.0%		1.0%
Klucel® H-PR <sup>7</sup>				1.3%	
Flash Point	133°F	168°F	182°F	176°F	186°F

\*Footnotes 1–7 refer to product sources.

blending and use of these formulas is available in the BASF publication, "Formulating Paint Strippers with N-methyl pyrrolidone."

## Applications

All of these formulations demonstrated good paint stripping ability in removing commonly used paints and coatings. During testing, performance data were developed on the ability of these products to strip acrylic latex, alkyd, polyurethane, and epoxy coatings from wood substrates.

Use of NMP paint strippers is similar to that of any other stripper. The product is applied to the substrate with a brush or roller and given sufficient time to penetrate the coating. A thickened version will strip walls or ceilings.

Following application, the residual stripper, paint flakes, and dissolved pigment are easily removed with a standard plastic or metal scraper. Since all of these products will slowly evaporate, the following procedure is recommended to ensure complete removal of spent solvent from surfaces:

- **Step 1:** After the stripper and paint have been scraped from the surface, wipe the area clean with a cloth or absorbent towel.
- **Step 2:** Using a wet cloth or towel, clean any residual formula from the surface. As these products rinse well with water, any residual solvent is easily removed.
- **Step 3:** Using a dry cloth or towel, remove any excess moisture and then allow the surface to air dry for several minutes.

For most projects, a single application of the stripper is sufficient, even when stripping thick (multiple) paint layers.

## Hazards

As stated earlier, one of the primary trade-offs is stripping speed versus solvent inhalation. One method for judging the relative risk of inhalation

is to compare the ratios of equilibrium vapor concentration (EVC) to permissible exposure limit (PEL, eight-hour average) for each solvent. These data are listed in Table 3.

**Table 3.—Vapor concentration data (@ 20°C).**

	EVC (PPM)	PEL (PPM)	RATIO
Methylene Cl	450,000	500	900
Methanol	130,000	200	650
Acetone	240,000	750	320
MEK	92,000	200	460
NMP	300	100*	3
Hisol® 15	1,300	100	13
EEP	1,400	50*	28
DBE	260	10*	26
Dowanol® TPM	25	—	—

\*Denotes producer's recommendation.

Higher ratio values indicate relatively higher risks of inhalation exposure. For instance, NMP's ratio of 3 versus methylene chloride's ratio of 900 indicates that the risk of inhaling a concentration of methylene chloride above the recommended PEL is 300 (900/3) times more likely than when using NMP under the same conditions.

In other words, NMP provides the user with a greater margin of safety from inhalation than the more common paint stripper solvents.

As with any solvent, rubber gloves must be used to prevent severe drying and potential blistering of exposed skin. If any skin comes into contact with an NMP blend, the exposed area should be immediately rinsed with water. Also, customers should use these products in well ventilated areas and wear goggles throughout the stripping process.

The NMP blends tested in this study have flash points in the range of 140° to 200°F. As such, all of these compositions result in combustible, but not flammable, mixtures.

## Product Performance

### Effectiveness

NMP-based formulas will effectively strip the following coatings:

- Acrylic latex gloss enamel
- Household epoxy spray paint
- Polyurethane gloss enamel
- High gloss polyurethane wood finish
- Tallow oil alkyd spray paint

In this study, the listed coatings were stripped from wood. These formulas also strip similar coatings from other substrates (metal, plastic, glass, concrete) effectively.

### Time Requirements

With sufficient time, NMP blends can be quite effective paint strippers. In some cases, these blends required longer contact time than conventional stripping formulations.

In general, the longer working times were required when stripping higher, crosslinked coatings. For certain blends, lowering the surface tension resulted in noticeably faster stripping.

To quantify the impact that surface tension has on stripping speed, the original five formulas were modified with a nonionic surfactant, Fluorad® FC-430. Shown in Table 4 are the original formulas modified to contain 0.2 weight percent of Fluorad® FC 430. Flash points of the new mixtures are listed as well.

Table 4.—Paint stripper formulas using Fluorad.®

	#1	#2	#3	#4	#5
NMP <sup>1*</sup>	31.0%	59.8%	79.8%	12.0%	49.8%
Hisol® 15 <sup>2</sup>	50.0%				
EEP <sup>3</sup>	17.7%	13.9%		6.7%	
DBE <sup>4</sup>		25.0%	12.0%	79.8%	36.0%
Dowanol® TPM <sup>5</sup>			7.0%		13.0%
Methocel® 311 <sup>5</sup>	1.1%	1.1%	1.0%		1.0%
Klucel® H-PR <sup>6</sup>				1.3%	
Fluorad® <sup>7</sup>	0.2%	0.2%	0.2%	0.2%	0.2%
Flash Point	138°F	174°F	184°F	180°F	194°F

\*Footnotes 1-7 refer to product sources.

After addition of the surfactant, each modified formula was compared to the original, unmodified version. The results of these tests are shown in Figure 1.

Table 5.—Comparative stripping times (minutes).

	ALKYD (3 LAYERS)	URETHANE ENAMEL (2 LAYERS)	HOUSEHOLD EPOXY (2 LAYERS)	ACRYLIC LATEX (2 LAYERS)	URETHANE FINISH (1 LAYER)
Formula #1:					
Unmodified	6-7	33	17	7-8	9
+ 0.2% Fluorad	7	33-34	16	7-8	8-9
Formula #2:					
Unmodified	<5	23	19	7-8	6
+ 0.2% Fluorad	5	20	13	7-8	6-7
Formula #3:					
Unmodified	7-8	26	14-15	7-8	4
+ 0.2% Fluorad	7-8	19	9	7-8	4-5
Formula #4:					
Unmodified	7-8	110	24	7-8	100
+ 0.2% Fluorad	7-8	67	20	7-8	96
Formula #5:					
Unmodified	7-8	42	17	7-8	9
+ 0.2% Fluorad	7-8	28-29	14-15	7-8	8-9
Methylene Chloride Formula					
Zip-Strip® <sup>8*</sup>	2.0	2.0	1.5	2.0	1.5

\*Footnote 8 refers to product source.

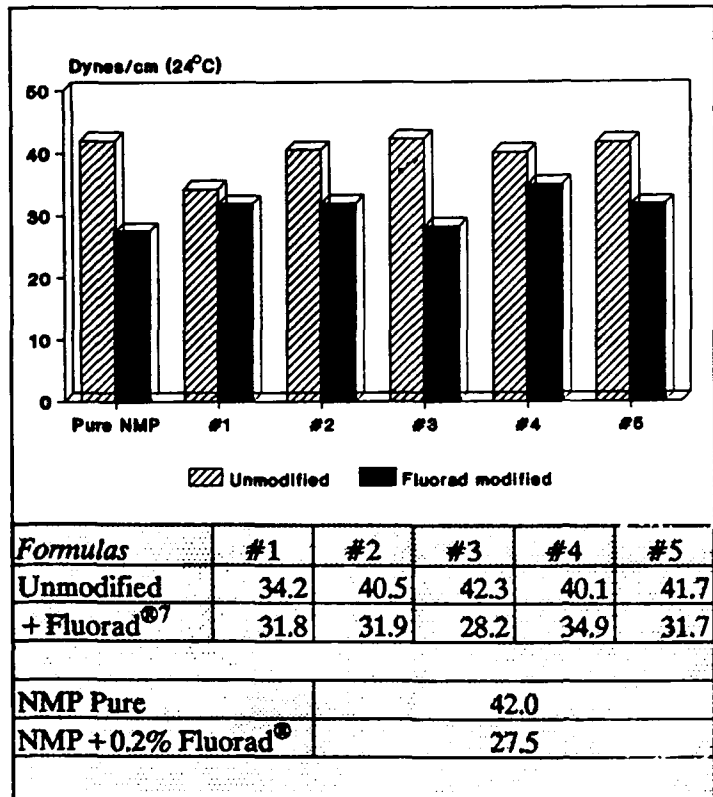


Figure 1.—Surfactant-induced surface tension reduction.

To measure relative performance, tests were conducted to observe the time required to lift various coatings from wood at room temperature. The modified NMP blends were tested against the original formulas, as well as Zip-Strip, a common methylene chloride-based product. Table 5 lists the results of these tests.

In actual use, those blends modified with Fluorad® demonstrated a noticeable improvement in stripping speed when removing urethane enamel and household epoxy, the more complex of the coatings tested. This increase in efficiency is illustrated by Figures 2 and 3.

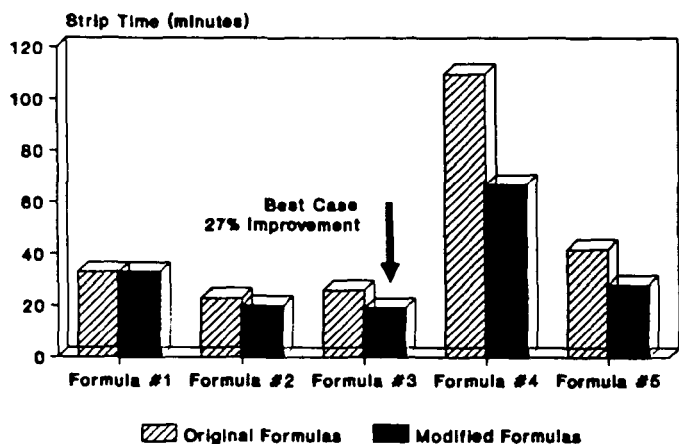


Figure 2.—Urethane stripping time improvement.

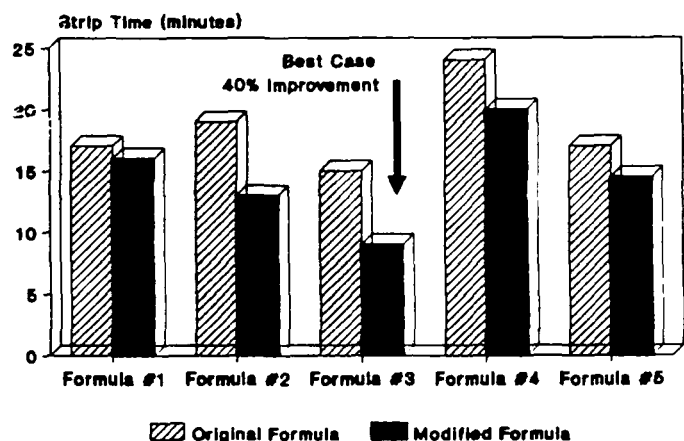


Figure 3.—Epoxy stripping time improvement.

Even after reducing the time required to strip urethane enamel and household epoxy, the NMP formulas are slower than the methylene chloride product. Again, the trade-off is one of stripping speed versus the possibility of solvent inhalation. NMP works slower but contains less solvent vapor.

## Waste Management

### Material Recyclability

A significant amount of the spent stripper is potentially reusable solvent. However, as this is a thickened mixture, conventional distillation techniques of recovery are unrealistic and any paper waste collected during use of the product further compounds the problem.

If a sufficient volume of thickened residue were isolated, a filter press could be used to separate the spent solvent, which could then be distilled and reused.

## Waste Generation

All of the compounds used in these NMP-based formulas have low vapor pressures. Until physically removed, a large amount of residue will remain on the substrate for a long time (Fig. 4).

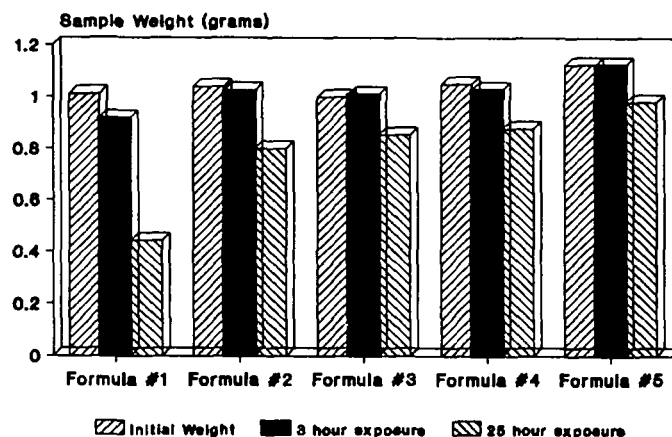


Figure 4.—Product remains on substrate.

As shown in Figure 5, relatively minor amounts of the stripper evaporate from the substrate, even after 25 hours.

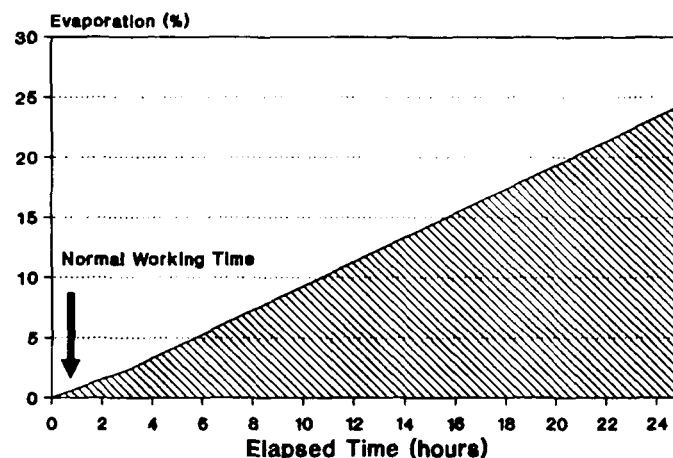


Figure 5.—Evaporation loss is minimal (long term).

In normal use, 15 to 30 minutes should be sufficient to remove most coatings. However, as further illustrated by Figure 6, 98 percent of the stripper will remain on the surface even after three hours. Most importantly, this low volatility significantly reduces the possibility of inhaling the solvent.

### Waste Disposal

When using these products, deposit the solvent or paint residue (as well as any paper or cloth debris) in a thick-walled polyethylene or polyvinylidene chloride bag.

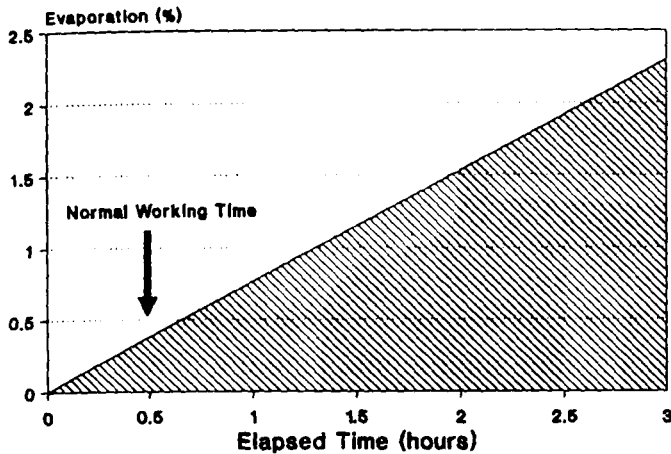


Figure 6.—Evaporation loss is minimal (short term).

In those areas of the country where household chemicals are sorted from other garbage, these bags of residue should be separated for proper disposal.

## Stripping Cost

Usage cost is another factor when developing NMP blends. Each of the five coatings examined in this study was removed in a single application of an NMP blend. The methylene chloride product, Zip-Strip, also removed each coating in a single application.

However, the volume of the NMP blend required for a single coat was approximately 38 percent less than that required to strip any given surface area. NMP strippers may be more expensive per gallon than traditional products. However, less product is required to achieve similar results. (See Fig. 7.)

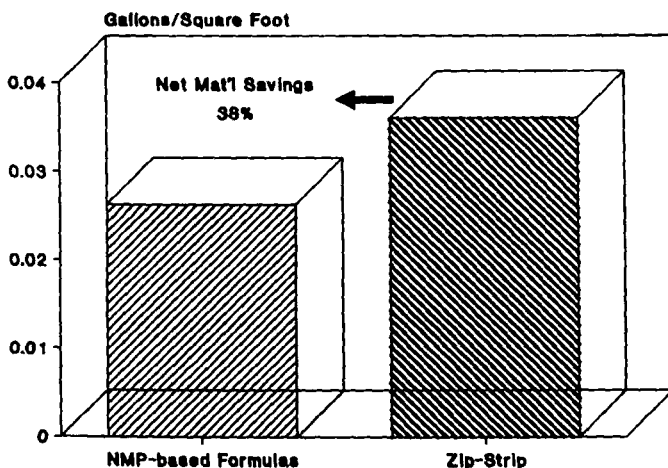


Figure 7.—NMP blends are more efficient.

## Summary

The search for alternative paint strippers will likely include several alternative solvents. In comparison to traditional paint strippers, the primary differences are issues of stripping speed versus the possibility of solvent inhalation and product cost versus usage cost.

- NMP blends work slower than traditional paint strippers, but NMP generates less vapor during the stripping operation than do the more common paint stripper solvents.
- NMP blends may be more expensive per gallon, but they will cover more surface area per gallon than will traditional paint strippers.

In evaluating replacements for traditional solvents, these trade-offs must be carefully reviewed before selecting and using an alternative paint stripper. In some applications, stripping speeds of NMP-based formulas can be improved by lowering the surface tensions of the blends.

## References

- Flick, E.W. 1985. Pages 469-73, 492-98 in *Industrial Solvents Handbook*, 3rd ed. Noyes Data Corp.
- Monick, J.A. Pages 70-72 in *Alcohols, Their Chemistry, Properties, and Manufacture*. Reinhold Book Corp.
- Riddick, J. A. 1986. *Organic solvents: physical properties and methods of purification*. Pages 36-40 in *Techniques of Chemistry*, 4th ed. Vol. II. Wiley-Interscience Publ. New York.
- Weast, R.C. 1989. Pages F-88, D-274-80 in *CRC Handbook of Chemistry and Physics*, 69th ed. CRC Press.
- Product Information Brochure: Fluorad® Coatings Additives FC-430, FC-431, 3M Industrial Chemical Products Division, issued 11/89.

## Product Sources

1. BASF Corporation, Parsippany, NJ.
2. Ashland Chemical Company, Columbus, OH.
3. Eastman Chemical Products, Inc., Kingsport, TN.
4. Dow Chemical Company, Midland, MI.
5. E.I. du Pont de Nemours & Company, Wilmington, DE.
6. Hercules, Inc., Wilmington, DE.
7. 3M Industrial Chemical Products Div., St. Paul, MN.
8. Star Bronze Company, Alliance, OH.

Hisol® is a registered trademark of Ashland Chemical Co. Dowanol® and Methocel® are registered trademarks of Dow Chemical Co. Klucel® is a registered trademark of Hercules, Inc. Fluorad® is a registered trademark of 3M Corporation.

## Appendix A: Sample Preparation

### *(3) Layers of Alkyd:*

A 2" x 8" x 10" piece of white pine board was sanded and then cleaned of all dust. The board was then spray painted with three thick coats of alkyd spray paint with 24 hours drying time between each application.

Coat 1: a green Tallow oil alkyd spray paint manufactured for Hardware Wholesalers, Inc. (HWI) 2012 green HWI No. 789-855, Lot #F033.

Coat 2: a brown Tallow oil alkyd spray paint manufactured for Hardware Wholesalers, Inc. (HWI) 2036 brown HWI No. 789-757, Lot #6174-2734.

Coat 3: the same green described above.

Reference: BASF Laboratory notebook - August 27, 1988.

### *(2) Layers of Household Epoxy:*

A 2" x 8" x 10" piece of pressure-treated wood was sanded and then cleaned of all dust. Two coats of epoxy spray paint were applied to the surface. A drying time of 72 hours was allowed between coats. Before application of the second coat, the first coat was lightly sanded and cleaned of all dust.

Coat 1: NYBCO Epoxy Spray Paint Code #1901 Appliance Snow White, lot # CP-81, manufactured by: New York Bronze Powder Co., Inc., Elizabeth, NJ.

Coat 2: NYBCO Epoxy Spray Paint Code #1912 Coffee Brown, lot # BC-72, manufactured by: New York Bronze Powder Co., Inc., Elizabeth, NJ.

Reference: BASF Laboratory notebook - September 19, 1988.

### *(2) Layers of Acrylic Latex Enamel:*

A 2" x 6" x 8" piece of white pine board was sanded and then cleaned of all dust. The board was then painted with two coats of acrylic latex gloss enamel. The paints were applied with a polyester bristle brush. A 24 hour dry time was allowed between each application. Also, the surface of the first coat was lightly sanded and cleaned before the second coat was applied.

Coat 1: JET-DRI<sup>®</sup> Acrylic Latex Gloss Enamel Code #00, Gloss White lot #AEA10 13E048, manufactured by: Desoto, Inc. Des Plaines, IL.

Coat 2: JET-DRI<sup>®</sup> Acrylic Latex Gloss Enamel Code #33, Azure Blue, manufactured by: Desoto, Inc., Des Plaines, IL.

Reference: BASF Laboratory notebook - September 19, 1988.

***(2) Layers of Urethane Enamel:***

A 2" x 6" x 8" piece of white pine board was sanded and then cleaned of all dust. The board was then painted with two coats of urethane enamel. The paints were applied with a polyester bristle brush. Coat # 1 was lightly sanded and cleaned of all dust prior to application of the second coat, 24 hours later.

**Coat 1:** JET-DRI<sup>®</sup> Polyurethane Gloss Enamel Code #17 Autumn Brown Lot #AE112 13048, manufactured by: Desoto, Inc., Gainesville, TX.

**Coat 2:** JET-DRI<sup>®</sup> Polyurethane Gloss Enamel Code #00 Gloss White Lot #AE 132 13E033, manufactured by: Desoto, Inc., Gainesville, TX.

Reference: BASF Laboratory notebook - September 19, 1988.

***(1) Layer of Urethane Wood Finish:***

A 2" x 6" x 24" piece of white pine board was sanded and then cleaned of all dust. The board was then painted with polyurethane stain, which was covered with a urethane high gloss top coat. Both stain and top coat were applied with a polyester bristle brush. Time between application of stain and top coat was 24 hours. The stain coat was very lightly sanded and cleaned of dust prior to top coat application.

**Stain:** High gloss polyurethane varnish stain Code # 61, Dark Oak Lot # 7568500612, manufactured by: Red Devil Paints and Chemicals, an Insilco Company, Mt. Vernon, NY.

**Top Coat:** High Gloss Polyurethane Code #70 , Clear lot # 75685 00702 , manufactured by: Red Devil Paints and Chemicals, an Insilco Company, Mt. Vernon, NY.

Reference: BASF Laboratory notebook - September 19, 1988.

JET-DRI<sup>®</sup> is a registered trademark of Desoto, Inc., Des Plaines, IL.

## Appendix B: Surface Coverage Comparison

### *Zip-Strip Sample*

A piece of finished oak board was measured and weighed. A coating of Zip-Strip was then applied with a polyester bristle brush. The total surface of the wood was coated with the same thickness of the stripper. (All thin spots in the Zip-Strip layer were filled in.) A single application was required to lift the finish that was on the surface of the oak substrate. The resin system of the finish was not known.

Measurement of board: 6" x 4" x 3/4"

Weight of board alone: 227.51g

Weight of board + Zip Strip: 254.62g

- $6" \times 4" = 24 \text{ in}^2$  of surface coated with Zip-Strip
- $27.11\text{g at } 1.181 \text{ g/cc} = 22.955 \text{ cc}/24 \text{ in}^2$
- $144 \text{ in}^2 = 1 \text{ square foot} = 137.73 \text{ cc}$

### *NMP Formula Sample*

A piece of finished oak cut from the same board described above was measured and weighed. A coating of Formulation 4 (see Table 2) was applied with a polyester bristle brush. The total surface of the wood was coated with the same thickness of stripper. A single application was required to lift the finish away from the oak.

Measurement of board: 9 5/16" x 4" x 3/4"

Weight of board alone: 291.37g

Weight of board + Formulation 4: 319.58

- $9 \frac{5}{16} \times 4" = 37.25 \text{ square inches coated with Formulation 4}$
- $28.21\text{g at } 1.0962\text{g/cc} = 25.73 \text{ cc}/37.25\text{in}^2$
- $144 \text{ in}^2 = 1 \text{ square foot} = 99.46 \text{ cc}$

1000 cc = 1 liter = 1.057 quarts

NMP technology will cover 38.05 square ft/gallon (single application)

$1000\text{cc}/99.46\text{cc} = X \text{ sq ft/sq ft}$

$X = 10.054 \text{ square ft / liter}$

$10.054 \text{ sq ft}/X = 1.057 \text{ quarts}/4 \text{ quarts}$

$X = 38.05 \text{ square ft/gallon}$

Zip-Strip will cover 27.48 square ft/gallon (single application)

$1000\text{cc}/137.73\text{cc} = X \text{ sq ft/sq ft}$

$X = 7.26 \text{ square ft/liter}$

$7.26 \text{ sq ft}/X = 1.057 \text{ quarts}/4 \text{ quarts}$

$X = 27.48 \text{ square ft/gallon}$

A gallon of NMP formula will cover 38.46% more surface area than a gallon of Zip-Strip.

# Woodfinisher's Pride: An Alternative to Current Chemical Paint Strippers

**Steve Johnson**

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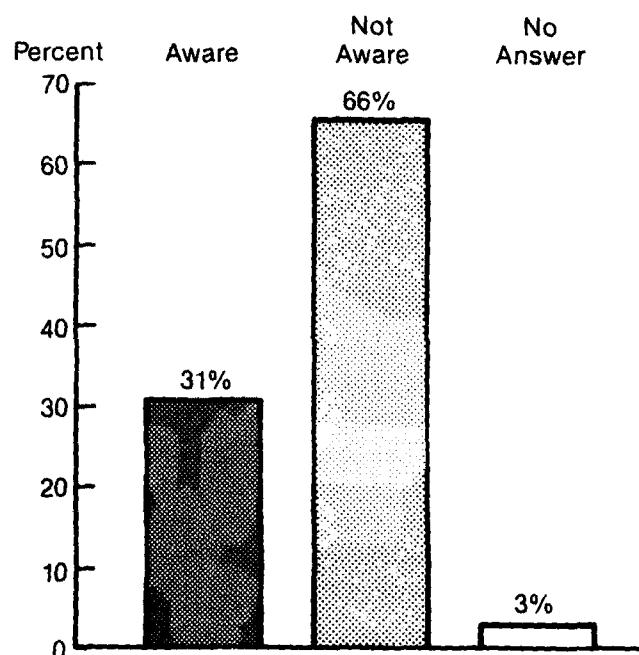
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## Current Technology and Environmental Concerns

During the last five years, methylene chloride, the active ingredient that has been used in chemical paint strippers since the 1970s, has come under increasing scrutiny for its potential to damage human health and the environment. Methylene chloride has been shown to be an extremely toxic chemical, and emissions and wastes resulting from its use must be disposed of under EPA's hazardous waste guidelines. Furthermore, it has been linked to the development of cancer in animals, although its effect as a carcinogen on humans has not been proven.

Environment is becoming a consumer issue. Effective products are no longer enough. Surveys suggest that consumers will pay more for products that do not pose health and environmental risks (see Tables 1, 2, and 3 and Fig. 1 for results of consumer surveys). These issues have led manufacturers to search for alternative methods of stripping paint.

Many of the products that have been formulated to meet these needs have been marketed without being thoroughly tested and evaluated. Although some of these preparations do seem safer, performance is markedly inferior to standard removers. In fact, it is rare to find a product that is both safe and effective, and in some cases, alternatives contain chemicals that are equally as hazardous as methylene chloride.



Source: National Tracking Study, 1990, Creative Technologies Group, Inc.

Figure 1.—Methylene chloride awareness (n=334).

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## Woodfinisher's Pride: A True Alternative

Woodfinisher's Pride is an alternative to methylene chloride paint strippers that is both safe and effective (see Tables 4 and 5 for summaries of Woodfinisher's Pride's performance and toxicity attributes). Its qualities make it an excellent health and environmental choice—it can be used indoors

**Table 1.—Characteristics of survey respondents. (n = 334)**

AGE	PERCENT
18–24	10
25–34	32
35–44	30
45–64	15
55–64	13
Median Age =	37.0
SEX	PERCENT
Male	54
Female	46
INCOME	PERCENT
< \$15M	4
< \$25M	12
< \$40M	34
< \$50M	18
< \$60M	8
< + \$60M	10
No answer	14
Median income	\$36,800

Source: National Tracking Study, 1990, Creative Technologies Group, Inc.

**Table 2.—Opinion of methylene chloride among aware respondents.**

OPINION	PERCENT
Dangerous	64
Not environmentally safe	27
Carcinogen	18
Smell	14
Fumes	9

Source: National Tracking Study, 1990, Creative Technologies Group, Inc.

with adequate ventilation, has low toxicity, is non-flammable and biodegradable, and cleans up with soap and water. The active ingredient in the product, *N*-methyl pyrrolidone (NMP), has been used industrially for over 25 years, and thus has over a quarter century of testing and usage to substantiate claims (see Fig. 2).

The product was not previously brought to the consumer market because it is relatively expensive and early formulations performed poorly. Now, the Creative Technologies Group, Inc., has successfully developed a formula for consumer use at a

**Table 3.—Unmet paint stripping consumer needs (n = 334).**

	IDEAL PRODUCT	CURRENT PRODUCT	DIFFERENCE (GREATEST PRODUCT OPPORTUNITIES)
Safer around children	8.57	5.71	2.86
Nontoxic	8.61	6.21	2.40
Biodegradable/environmentally safe	8.72	6.54	2.18
Easily removable from curves or corners	8.58	6.61	1.97
Nonpoisonous	8.61	6.67	1.94

Source: National Tracking Study, 1990, Creative Technologies Group, Inc.

Key: 10 = Extremely Important  
1 = Not at All Important

Product Formulations	Biodegradable
Product Formulations Removed Coatings/ Finishes	Mixture assumes the disposal status of the particular coating (EPA TCLP Procedure)
Product Packages	Polyethylene + nylon (recyclable)
Reuse of Packages	User receives \$1.00 for each container returned for reuse/ recycling

Source: Creative Technologies, Inc.

**Figure 2.—Woodfinisher's Pride environmental attributes.**

competitive price and created an effective market strategy for the product.

Woodfinisher's Pride is a paint and varnish stripping gel. The product is suitable for wood, glass, and metal, and can remove lacquer, acrylic, polyurethane, alkyd enamel, shellac, latex, varnish, and epoxy. Because traditional methylene chloride strippers evaporate twice as fast as Woodfinisher's Pride (and require "patchwork applications"), Woodfinisher's Pride is actually 27 percent less expensive to use than the other products. In most cases, it removes multiple layers of coatings in 30 minutes with no reapplication (see Table 6 for a cost comparison of Woodfinisher's Pride with traditional strippers). With a rate of evaporation 360 times slower than methylene chloride, the product stays wet for hours, thus extending flexibility of use. It does not leave a waxy residue, as do many strippers, and will not raise wood grain or lift veneers because it does not contain any water.

## Primary Ingredients

Woodfinisher's Pride for paint works by swelling the polymer bonding paint to the substrate, caus-



**Table 7.—N-methyl pyrrolidone, (primary ingredient in Woodfinisher's Pride) irritation and toxicity tests results.**

TESTS	RESULTS
Acute oral toxicity (LD-50 on a variety of species)	Low order of toxicity
Subacute feeding studies (Wistar rats, Charles River mice, beagle dogs, game birds)	Low order of toxicity
Skin irritation/chronic dermal toxicity (rabbits, humans, guinea pigs)	Skin irritant
Ocular toxicity	Eye irritant
Inhalation hazard testing (cats, rabbits, guinea pigs, rats, mice)	No effect (even at saturation)
Injection toxicity	Low
Carcinogenicity/mutagenicity studies (Ames Test, Mouse Lymphoma Assay, CHO Forward Mutation Assay, Unscheduled DNA Synthesis Assay)	Inactive
(2-year inhalation study)	No activity
Embryotoxicity/teratology studies	Not teratogenic/embryotoxic at high levels (1g/kg)
Toxicity to aqueous organisms	Low
Pharmacokinetics	Rapidly excreted
Biodegradation	Highly biodegradable
Regulatory approval	Jan. 1985 (40 CFR 180-1001 (D) Pending
EPA preharvest approval	Approved (21 CFR 176.300) GRAS
EPA postharvest approval	
FDA slimicides-indirect food additive	

Source: Creative Technologies Group, Inc.

## Comparison with Other Products

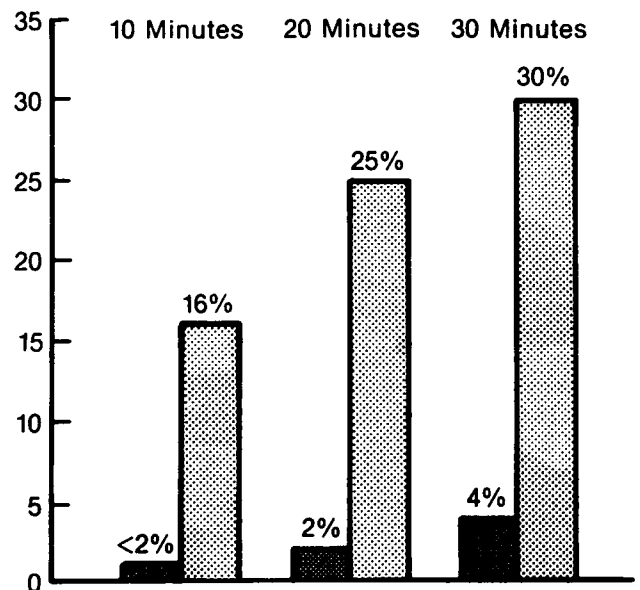
### Methylene Chloride Strippers

Woodfinisher's Pride does not contain methylene chloride or other flammable or toxic chemicals; as a result, the fumes are not dangerous when inhaled, and it does not require extreme ventilation. Also, Woodfinisher's Pride does not evaporate quickly, so pieces do not have to be stripped in sections (see Figs. 3, 4, and 5 for comparison of Woodfinisher's Pride with traditional methylene chloride strippers).

### Nonmethylene Chloride Strippers

With the exception of products containing dibasic esters, strippers presently being used as a substitute for methylene chloride products contain other harmful and flammable ingredients such as methanol, toluene, and acetone. Dibasic ester products such as 3M's Safest Stripper are difficult to apply, require several hours for the product to work, and contain a high percentage of water, which is damaging to wood substrates.

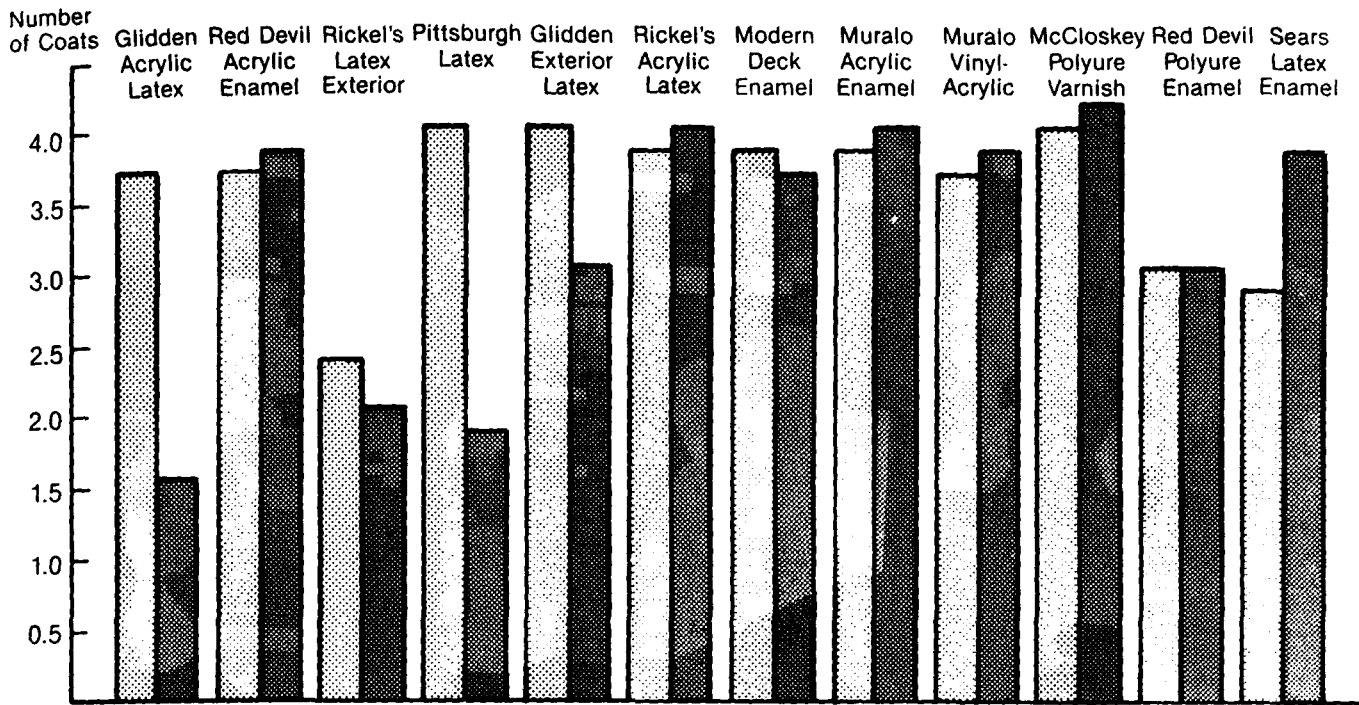
% Weight Loss of Formulation



Source: Creative Technologies Group, Inc.

Key:  Woodfinisher's Pride  
 Traditional Strippers

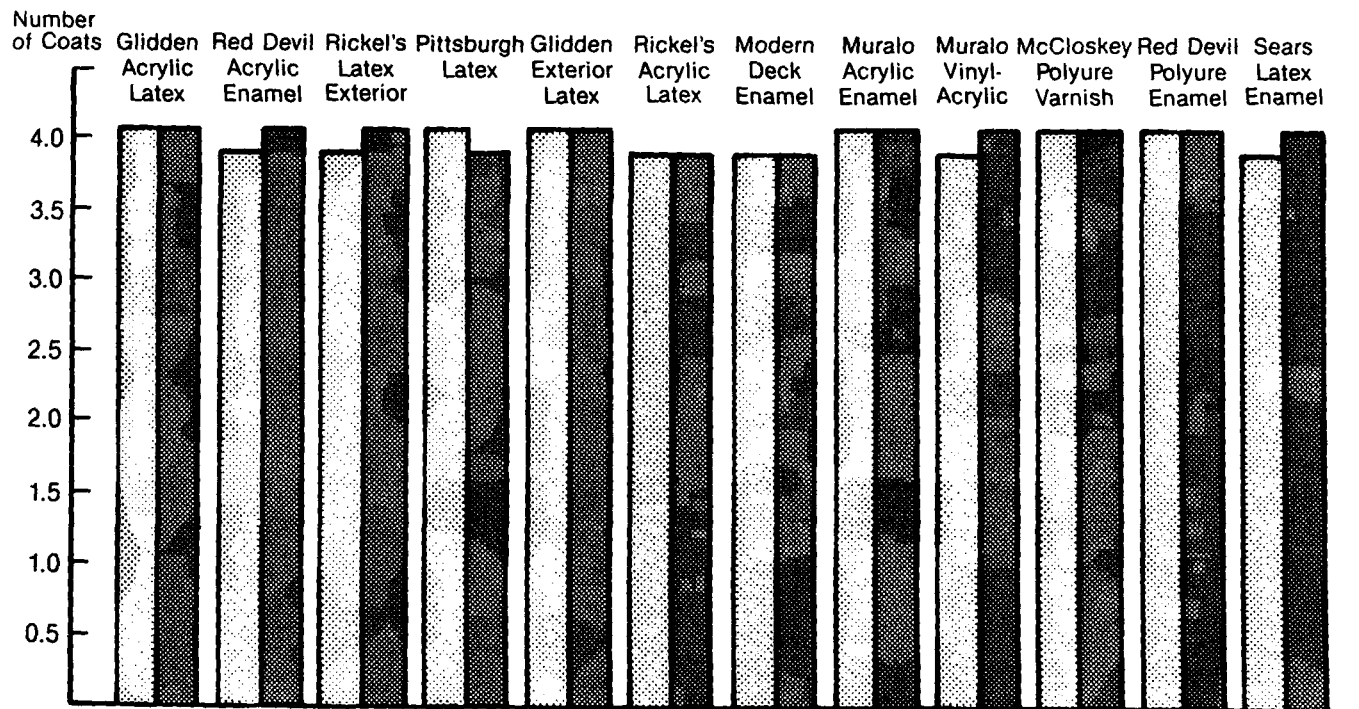
**Figure 3.—Formulation volatility comparison of Woodfinisher's Pride vs. traditional strippers.**



Source: Creative Technologies Group, Inc.

Key: Traditional methylene chloride strippers Woodfinisher's Pride

Figure 4.—Performance of Woodfinisher's Pride vs. traditional methylene chloride strippers after elapsed time of 15 minutes.



Source: Creative Technologies Group, Inc.

Key: Traditional methylene chloride strippers Woodfinisher's Pride

Figure 5.—Performance of Woodfinisher's Pride vs. traditional methylene chloride strippers after elapsed time of 30 minutes.

## Conclusion

Woodfinisher's Pride is a high-performance product that is safer for the environment and the user than methylene chloride preparations. While the health consequences of methylene chloride are

still being debated, Woodfinisher's Pride is an alternative that can provide excellent results and generate good profits for retailers. Tables 8 and 9 compare response to Woodfinisher's Pride and a leading methylene chloride brand.

**Table 8.—Consumer study of Woodfinisher's Pride vs. Formby's/Strypeeze for stripping surfaces (N = 55, side-by-side use).**

ATTRIBUTE	WOODFINISHER'S PRIDE	METHYLENE CHLORIDE
Able to coat entire surface	7.73 *	6.50
Able to use inside	8.94 *	6.27
Biodegradable/safer to use	8.80 *	4.68
Able to clean up with water	8.50 *	5.57
Right consistency for vertical surfaces	8.48 *	5.64
Able to reuse applicator brush	8.42 *	5.73
Easy to use	8.24 *	6.47
Having a pleasant scent	8.06 *	4.91
Easy removal from surfaces	7.80 *	6.22
Safer around children	7.35 *	4.70
Easy removal from curves/corners	7.07 *	5.29
Easy removal of several layers	6.89 *	5.22
Overall Attribute Evaluation:	7.73 *	6.50
Overall Preference:	71% *	27%

Source: Consumer Usage Study, Creative Technologies Group, Inc.

Note: Paints tested were enamel, polyurethane, alkyd, latex, and acrylic.

\* = Statistically significant at the 95% confidence level.

Key: 10 = Most satisfied

1 = Least satisfied

**Table 9.—Consumer Study of Woodfinisher's Pride vs. Formby's/Strypeeze for stripping varnished surfaces (N = 157, side-by-side use).**

ATTRIBUTE:	% PREFERRING WOODFINISHER'S PRIDE	% PREFERRING METHYLENE CHLORIDE
Biodegradable/safer for environment	94	4
Able to clean tools with soap/water	93	1
Easy to clean up	92	6
Having a pleasant scent	90	3
Able to use inside	89	8
Right consistency for vertical	87	13
Able to coat entire surface at once	86	13
Easy to use	83	11
Safer around children	83	11
A good value for the money	72	21
Removing coatings easily	65	28
Taking less time to do project	59	38
Able to remove several layers of varnish	58	39
Overall Preference	62%	31%

Source: Consumer Usage Study, MARKETING SPECTRUM.

Note: Varnishes tested were polyurethane and shellac.

# Bix Stripper: An Alternative to Methylene Chloride

**Gerald L. Bixenman**

*Bix Manufacturing Company  
Ashland City, Tennessee*

**T**he risks from using paint strippers containing methylene chloride are among the highest ever calculated for chemicals from consumer products.

This statement from a 1985 Consumer Products Safety Commission news release was widely quoted in the media and discussed on celebrity and talk shows.

The claim that there was no viable alternative to methylene chloride was stated or implied in virtually all of these accounts, but no source was ever mentioned.

There is, however, a viable alternative that has been sold successfully for almost 30 years: Bix Stripper, a stripper that has never contained methylene chloride.

While Bix Stripper will not remove epoxy, the coating most frequently encountered by retail customers is cellulose lacquer.

In fact, Bix Stripper is far superior to methylene chloride formulations as a stripper of lacquer, polyurethane, varnish, and shellac. Epoxy-type coatings are seldom encountered on furniture, cabinets, woodwork, and pianos that

retail consumers work on; they are usually found in industrial and business situations.

Bix Stripper "melts" paint and finishes rather than "blisters" them. The air that gets under the blisters causes methylene chloride removers to dry out quickly. In contrast, when the coating is "melted" air cannot get under it, so it remains wet and keeps working much longer.

Most methylene chloride strippers are designed to remove the top coat. Repeat applications to remove multiple coats require more work and much more remover. Bix Stripper's melting feature enables the consumer to remove the bottom coat first, thus requiring less work and much less stripper.

Bix Stripper is used extensively in interior restoration. Its slow evaporation cuts vapor emissions to a minimum, while removing the bottom coat first saves a great deal of labor and material. Bix stripper is sold in over 75 percent of home centers, all hardware cooperatives, most hardware and paint sundry distributors, and hundreds of paint stores. It outsells methylene chloride formulations in most areas. There is a viable alternative!

# Substitute Chemical Formulations for Professional Furniture Refinishing

**David L. White**

*Kwick Kleen Industrial Solvents Inc.  
Vincennes, Indiana*

**K**wick Kleen Industrial Solvents manufactures industrial paint removers for the commercial trades. According to a recent CONSAD report contracted for by the Occupational Health and Safety Administration, Kwick Kleen products consume 7 percent of the methylene chloride used in this industry. Kwick Kleen's products are sold throughout the United States and Western Europe for use in furniture refinishing and restoration, original equipment manufacturer recycling of rejected parts, and general recycling or manufacturing of durable goods.

Kwick Kleen manufactures removers in six chemical groups: non-flammable methylene chloride, petroleum base and oxygenates (with less than 20 percent methylene chloride), non-methylene chloride proprietary, *N*-methyl pyrrolidone, aqueous, and caustics.

Kwick Kleen has experimented with the following chemicals, which are being promoted as possible substitutes for methylene chloride:

- Alkyl acetates
- Diacetone alcohols
- Dibasic esters
- Furfuryl alcohols

- Monochlorobenzene
- Monochlorotoluenes
- Monoethanolamine
- Methyl amyl ketone
- *N*-methyl pyrrolidone
- Propylene glycol monomethyl ether
- Acetate trioxane

Only *N*-methyl pyrrolidone and a combination of two of the above sold as a non-methylene chloride proprietary blend by Kwick Kleen show any promise for use in the furniture trades.

Because of the characteristics of wood and the many finish treatments, paints, and combinations of both that may have been applied to an item, paint removal from the substrate poses unique problems. There are 13 different types of groups of clear finishes and over 30 different finishes. Add paints, and there are thousands of combinations that could be on the surface of the furniture.

A marketable remover must meet 25 paint remover characteristics before it can be introduced as a Kwick Kleen product. Recent tests were performed on four types of finish coatings: stained

and varnished, stained and lacquered, multiple coats of enamel paints over clear varnish, and acrylic paint over stain and varnish. The first three items were chairs and the fourth a measured area on a flat surface.

Tests used the flow-over method. The time stripped in minutes, percent of coating removed, percent of stain removed, color to substrate (wood), and percent of chemical bleed-out after stripping are shown in the following table:

REMOVERS	COATINGS			
	STAIN & VARNISH	STAIN LACQUER	VARNISH ENAMEL 3 COATS	STAIN VARNISH 1 COAT ACRYLIC
Methylene chloride	5	19	32	9
% coating	100	99	100	100
% stain	100	95	100	100
Color substrate	Natural	Stain	Natural	Natural
% bleed out	0	0	0	0
Proprietary	11	24	39	27
% coating	100	100	95	97
% stain	95	90	100	100
Color substrate	Stain	Stain	Natural	Natural
% bleed out	0	0	5	0
N-methyl pyrrolidone (NMP)	15	45	37	54
% coating	100	100	95	95
% stain	20	80	100	20
Color substrate	Stain	Stain	Yellow	Stain
% bleed out	0	0	5	5
Dibasic esters (DBE)	14	118	138	136
% coating	100	75	95	95
% stain	5	5	100	5
Color substrate	Stain	Stain	Yellow	Stain
% bleed out	0	0	5	5

Labor varied from one re-coat for methylene chloride to 28 re-coats for the DBE remover. Scrubbing was limited to no more than three tries to allow the remover to do its work. When compared to the methylene chloride blend during this test, the proprietary blend required 17 percent more time, the NMP 20 percent more, and the DBE took four times as long.

Each of the substitutes is more labor-intensive and costs considerably more than methylene chloride removers. The current prices per gallon in 55-gallon drums of the removers tested are as follows: methylene chloride blend, \$4.95; proprietary blend, \$8.00; N-methyl pyrrolidone blend, \$12.09; and the dibasic ester blend, \$17.95. The amount of remover used was 2,874 ml of the methylene chloride blend, 2,164 ml of the proprietary blend, 1,710 ml of the N-methyl pyrrolidone, and 2,043 ml of the dibasic ester. Sludge from the methylene chloride blend was air-dried to a hard solid for land-fill disposal;

sludges from the other blends required hazardous disposal because they were wet and flammable.

It is extremely important to dispose of sludge properly because both the remover and paint sludge pose threats to human health and the environment. Depending upon the thickness of paint sludge, methylene chloride can evaporate within hours, leaving dried paint and trace residues of solvents. Thickeners will also be present if the formula was a semi-paste.

Because of the low volatility of solvents found in N-methyl pyrrolidone, DBE, and most other substitutes, drying time extends into days. Paint sludge removed from an 80-square-inch test panel at the Kwick Kleen laboratory remained wet for over 60 hours; inspection of the sludge disclosed continued solvent activity.

Kwick Kleen has determined that sludge disposed of while wet into a land fill poses an environmental threat because it includes solubilized heavy metals, such as lead. EPA must consider the environmental impact of millions of gallons of wet paint sludge as compared to that of dried paint chips of methylene chloride-based paint removers.

To rebut a negative statement about the Flowover<sup>®</sup> system, repeated tests have shown that wood soaked in a paint remover absorbs up to 80 to 90 percent more solvent than wood exposed to paint remover that has been applied by brush or Flowover<sup>®</sup> pump. With a pump system, interior areas of desks and chests of drawers, undersides of tables, or unfinished, unexposed areas of items are wetted once with remover to prevent stains from runs. The finish is then scrubbed away with the remover, which is applied through the brush and directed only to the surface where needed. In a soak tank, all areas of the item, including the unfinished inside, are exposed to and absorb the chemicals while the remover is working on the finished surfaces.

Furniture can be stripped 20 to 30 percent faster with a Flowover<sup>®</sup> brush than in a soak tank because of the brush's abrasiveness and the cutting action of the remover flowing through it. Moreover, proper ventilation is easily achieved with a Flowover<sup>®</sup> system because fumes can be drawn from around and underneath the work table. Research done by the National Institute for Occupational Safety and Health indicates that 85 percent of the industry uses a pumped flow method to apply remover.

Lastly, the only equipment-related fatalities in this industry have occurred when workers fall into tanks or are overcome by chemicals when leaning into tanks. In the Flowover<sup>®</sup> system, remover is pumped into a tray at an optimal working height,

thereby eliminating the need for employees to lean down into the tank.

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## Conclusion

Methylene chloride is the only suitable paint and coating remover that is non-flammable. This is of considerable concern to most users since many coatings are lacquers containing nitrocellulose that, when mixed with a flammable remover, become a substance similar to napalm.

Because workers must be close to the work and normally have the remover on gloves, apron, and boots while working, a fire often results in

death. The National Fire Protection Association data on fires in furniture repair shops from 1984 to 1988 show an average of one death and three injuries each year. A death for each 100 fires is very high when compared to other business fires.

With the industry currently using only 5 percent flammable paint removers, it would be a conservative estimate to increase the number of deaths in proportion with the use. If the industry converted to 100 percent flammable removers, the number of deaths could rise to 15 and injuries to 45 per year. However, these figures do not take into account the increase in hours that would result from the slow cutting speed of the substitute paint removers.

# An Alternative to Methylene Chloride for Removal of Lead-based Paint

**Stephen C. Arndt**  
*Arndt Brothers Industries*  
*Milford, Connecticut*

**H**ousing authorities and environmentalists nationwide are demanding the removal of lead-based paints from dwellings and other structures in response to the increased recognition of lead poisoning hazards. The ingestion of lead in the form of paint chips and dust can cause neurological damage, especially in children and fetuses. In recognition of this hazard, lead-based paints have been banned since the 1970s, but the problem of removing such paint from older homes, public buildings, and steel industrial structures, such as water tanks, remains.

Until recently, the paint removers used most widely contained blends using methylene chloride, a substance that in itself poses substantial environmental and health risks. These substances required multiple applications and are not suitable for lead-based paint removal because of these hazards and the problems created for disposing of the resultant mixed hazardous waste.

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## An Alternative Method of Paint Removal

A new form of caustic paint removers has proven more effective and much safer, providing a "minimum of chemical with the maximum effect." In the late 1980s, a method called the Peel Away Paint Removal System was developed by Dumond Chemicals, Inc., and has gained wide acceptance among housing authorities and other groups challenged with large-scale paint (especially lead-based) removal projects.

The chemical compound in Peel Away I is a thick alkaline paste that is spread or sprayed over lead-based paint. The paste is then covered with a laminated cloth provided by the manufacturer, which controls evaporation. The cloth is left on

until all the paint has emulsified; when removed, the paste and paint adheres to it, and the stripped surface is washed clean and neutralized.

Designed for the one application removal of multiple layers of paint from wood, brick, plaster, metal, concrete, stucco, cast iron, marble, or fiberglass, the system offers the advantages of safe and effective lead-based paint removal and containment. First, the paint is kept damp throughout the removal process, assuring that lead-based paint particles will not be dispersed throughout the atmosphere in the area being stripped. The paste, paint, and cloth are then removed intact, allowing for easy disposal. The paste contains no toxic fumes or flammable solvents.

Peel Away ST-1 is also effective on multiple layers of lead-based paint on steel structures; it adheres to all irregular surfaces and forms a self-sealed environment in about one hour. The alkalinity of the product protects stripped steel from corrosion. Peel Away contains a low percentage of caustic chemicals—about 7 to 8 percent. The paste form provides the ability to build thicknesses in proportion to the number of layers of paint being removed, ensuring a one-application process. The paste form eliminates danger from chemical splash, and there is no chemical runoff from unnecessary repeated applications. It also clings to overhangs and verticals, making the application process easier and safer.

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## Procedures and Cost

Proper set-up and procedure require dressing in a PVC suit, rubber gloves (taped to sleeve), a half face mask respirator (when removing lead-based paints), and eye protection. The system allows for potential hazardous materials to be kept separate, i.e., liquid from solid waste. Other considerations

include the potential for heat exhaustion among workers, especially those wearing chemical suits, and the availability of clean water for emergency use. A recent test on a four-bedroom apartment where lead-based paint was being removed by several methods showed no detectable exposure to lead by workers using the Peel Away method.

The process provides cost control as well. Since there is only one application, bids can be accurately assessed and compared. It is also possible to estimate the total material cost and the amount of by-products that will need disposal. The solid waste generated is roughly equal to that of material used (number of gallons of caustic paste remover). The loss of water from evaporation is compensated by the absorption of liquified paint and the fibrous laminated covering.

The liquid waste from the cleaning process varies from job to job and from contractor to contractor; specialized vacuum equipment will minimize the amount of water needed. High pressure is not necessary and not recommended. The procedure works best with a light spray and soft scrub brush.

As part of the Peel Away paste, there is a natural buffer to bind the lead, severely reducing the extent and rate in which these toxic metals could one day re-enter the environment. As the old paint is emulsified and enters a liquid phase, this allows for an exchange of ions between the lead and the buffers, forming a new compound, lead hydroxide. In most instances, these buffers will reduce the hazard classification as measured by the TCLP, most likely to either a special waste or even a non-hazardous level.

Peel Away is also especially effective for historical renovation projects, since it can penetrate deep grooves and crevices in decorative work. Approval should be sought from local historical commissions before beginning any such project.

Caustic paste paint removers are not suitable for hardwoods, veneer of plywood, aluminum, and some decorative plasters; they also have difficulty with epoxy coatings, urethanes, baked-on finishes, and latex-on-concrete. To minimize risks associated with a caustic paste remover, do a test patch on different substrates. The test will verify that the surface is suitable for the caustic paste removal process and will determine the level of corrosivity of solid and liquid wastes and the best method to treat or dispose of them. It will allow the user to determine the optimal thickness and time frame for the process. It will also allow testing for the best method for cleanup and subsequent coatings or refinishing.

## Projects Completed with Peel Away

A number of large-scale paint removal projects have recently been completed using the Peel Away method. In 1988, the Chattanooga Housing Authority, Chattanooga, Tennessee, began removing lead-based paint from more than 700,000 square feet in housing units throughout the city. The surface was 97 percent plaster, 2 percent wood baseboards, and 1 percent metal door cases and headers. The best all-around surfaces for stripping and containment with Peel Away were metal and plaster. Apartment units averaged 2,400 square feet, and six people were able to complete 7,200 square feet (approximately three units) per day. The project cost was \$2.75 per square foot stripped.

Texas A&M University at College Station used the Peel Away process to strip 16 four-story ROTC dorms. The surfaces were primarily rough porous plaster with a heavy latex coating and a nonlead paint abatement. Peel Away was applied with a Graco ram pump on 55-gallon drums with a 150-foot hose. With one person spraying and three or four persons applying the blanket, the average coverage was 10,000 square feet per day. Because of the roughness of the plaster, the larger portion of the crew was used for the final cleanup and rinsing of the walls.

Many historic renovation projects were also completed successfully using Peel Away to strip lead-based paint. One example, the First Church of Christ, Milford, Connecticut, was built in 1839. Its surface wood totals 19,500 square feet, and the steeple is 150 feet high. In one application, Peel Away successfully removed more than 20 layers of old lead-based paint. The contractor set cost at \$6.15 per square foot (total cost \$120,000), which included total removal of lead-based paint, removal of lead-lined hazardous waste, surface preparation, all necessary caulking and reglazing, one coat of oil primer, and two top coats of oil paint. The approximate cost for hazardous waste disposal was \$20,000.

Clearly, the new approaches to caustic removal of lead-based paint are economically viable, effective, and safe. Peel Away, a process developed by Dumond Chemicals, Inc., has been shown to be especially promising and effective in a variety of applications.

This presentation focused on Peel Away I and ST-1. However, Dumond Chemicals makes a multifaceted range of removal products that strip coatings from all types of surfaces.

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# **HOUSEHOLD & COMMERCIAL STRIPPING**

## ***Exposure Control & Pollution Prevention***

**Chair: Sandra Eberle**  
*Directorate for Program Management and Budget  
U.S. Consumer Product Safety Commission*

**Chair: Glenn Simpson**  
*Directorate for Economic Analysis  
U.S. Consumer Product Safety Commission*

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# Case Study: Control of Methylene Chloride Exposures During Commercial Furniture Stripping

Cheryl L. Fairfield

Amy A. Beasley

National Institute for Occupational Safety and Health  
Cincinnati, Ohio

**T**he furniture stripping industry includes an estimated 20,000 workers who are employed by approximately 6,200 small businesses, averaging three employees each. Furniture strippers, in general, do not have an occupational safety and health program as an integral part of their business. Therefore, these small businesses are unlikely to develop innovative controls to protect their workers.

At the National Institute for Occupational Safety and Health (NIOSH), researchers have documented time-weighted average exposures to methylene chloride in the furniture stripping industry ranging from 12 parts per million (ppm) to over 2,000 ppm. The institute recommends that methylene chloride be regarded as a potential occupational carcinogen and that methylene chloride be controlled to the lowest feasible limit. Researchers from the Engineering Control Technology Branch of NIOSH are therefore conducting field research to develop, document, and evaluate effective controls for methylene chloride in furniture stripping facilities.

NIOSH researchers implemented a control at one facility on a retrofit basis. Workers who stripped furniture in this facility using the existing ventilation system had exposures to methylene chloride of 600 to 1,150 ppm. NIOSH researchers designed, installed, and evaluated a new ventilation system (Fig.1), which incorporated these primary improvements:

- A new local ventilation hood,
- An increased amount of makeup air to the stripping area,

- Removal of a panel of charcoal filters that caused a pressure drop, thus hindering the effectiveness of the ventilation, and
- Improved work practices.

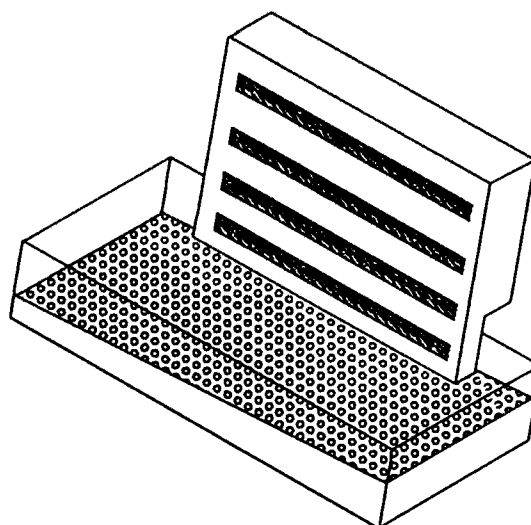


Figure 1.—New ventilation hood including a slot hood and a downdraft hood.

The new ventilation system was tested over three days with charcoal sorbent sampling tubes for methylene chloride. The sampling results indicated that the new ventilation system lowered exposures from 600 to 1,150 ppm to a geometric mean of 25 ppm, with lower and upper confidence intervals of 11 and 58 ppm, respectively (Fig. 2). Conclusions and recommendations at the end of the case study include the following:

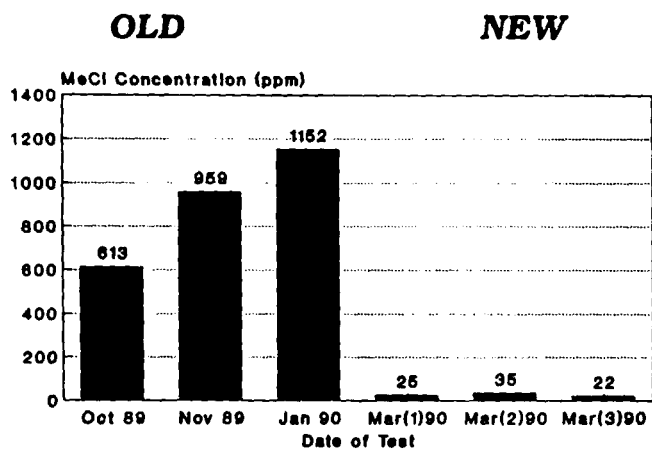


Figure 2.—Methylene chloride exposures for old and new control designs.

- This facility should use the installed local ventilation as a combined hood,
- Elimination of crossdrafts is an important factor in improved control, and
- Further reductions can be achieved by installing ventilation controls in the rinse area.

Several other surveys have been conducted of ventilation controls for methylene chloride in furniture stripping, and reports from these surveys are being prepared. In one study, a ventilation system was designed at the same time that a new stripping tank was installed. The additional design flexibility allowed for control to similar levels as this other case study but with considerably less exhaust air. A final report will be completed in late 1991.

# An Investigation of the Reduction of Methylene Chloride Volatility in Paint Strippers

**Eric L. Mainz**  
*Vulcan Chemicals*  
*Wichita, Kansas*

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## Introduction

In 1986, Vulcan Chemicals and Occidental Chemical initiated a research project at the University of Missouri-Rolla to identify additives that would reduce the evaporation rate of methylene chloride in paint remover formulations.

Research since 1988 has focused on developing a basic understanding of the evaporative process in these mixtures. To achieve this, an experimental matrix was created in which a model formulation was built up step by step. Common elements of commercial stripper formulations—methylene chloride, wax, thickening agent, methanol, and toluene—were added in successive matrix levels. At each level, additives that could reduce the evaporation of methylene chloride were included in comparative studies.

Researchers knew surfactants provided evaporation barriers in volatile organic liquids. Barrier enhancement was thought to be mainly a question of desolubilizing wax in a critical area of the solution near the surface. However, experiments with surfactants in complex stripper formulations did not show barrier enhancement. Relatively small polar molecules such as *N*-methyl pyrrolidone,  $\gamma$ -butyrolactone, and propylene carbonate showed some promise in preliminary tests using simple solutions of methylene chloride, wax, and other components.

In another approach, researchers tested glycerine as an additive because its mutual immiscibility with methylene chloride suggests it can form a liquid barrier film that could complement the wax barrier. Experimental results in more complex model formulations seem to have confirmed this concept. However, the effectiveness of

glycerine and the other additives depends on the balance of polar and nonpolar solvents. In limited testing, glycerine demonstrated barrier enhancement in some commercial formulations.

Both thermodynamic (equilibrium) and kinetic (dynamic) effects were considered. However, while lowering the equilibrium vapor pressure (i.e., the thermodynamic activity) can appreciably lower the evaporation rate, any drastic lowering will also affect methylene chloride's ability to penetrate and attack a coating. Therefore, the greatest chance of success appeared to lie with a study of the kinetics of evaporation.

Evaporation rates are usually controlled by creating a physical barrier between a liquid and the vapor space above. Incorporation of wax into the formulations is the most common way to form a barrier in commercial paint stripping products. Some previous studies on solid films, including waxes, have suggested that their brittleness could lead to erratic effectiveness. By contrast, a liquid form could be "self healing." The researchers' preliminary conclusion was that a combined liquid-solid film might provide the optimum barrier.

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## Experimental Procedures

### *Sample Preparation*

The desired quantity of wax was weighed into a tared bottle and the approximate amount of methylene chloride added to obtain the targeted wax concentration. This mixture was warmed in hot water, often bringing methylene chloride to a boil (in a fume hood) until the wax dissolved. The bottle was dried, its contents reweighed, and suf-

cient methylene chloride added to achieve the desired wax concentration.

If appropriate, a thickening agent was weighed into a 20 mL screwcap bottle and methylene chloride-wax solution added until solution volume totaled 15 mL. The solution was shaken and reweighed before adding other components or additives.

All samples were allowed to stand overnight before evaporation rates were measured. By the next day, the samples had usually gelled and, in many cases, some of the wax had formed a separate layer.

## Materials

Aldrich HPLC grade methylene chloride was used in all formulations. Several different waxes were used: a pure paraffin canning wax; a slightly softer, lower-melting, microcrystalline wax (the so-called "slack wax"); and simulated slack wax that was prepared by mixing the paraffinic canning wax and 5 to 20 percent hexadecane. Commercially available samples of hydroxypropyl cellulose (S23) and ethylhydroxyethyl cellulose (S105) were used as thickening agents. Hydroxypropyl cellulose was favored because it gelled more consistently in the presence of methylene chloride and other components or additives. Unless otherwise noted, the common chemicals were purchased from Aldrich or Fisher. Surfactants were generally made available by the manufacturer.

## Equipment

Samples were evaporated from glass petri dishes, approximately 9 cm in diameter and 1 cm deep, that were topped with a slightly larger dish or loosely fitted cover. Samples were weighed on a Sartorius Top-Loading Balance, Model 1205 MP, readable to 0.001 gram, that was interfaced to a strip chart recorder (full scale = 2 grams).

Since it was hard to take accurate weighings in the fume hood, researchers put a baffle around the petri dish. Initially, the baffle was made out of a two-pound coffee can with a hole one inch in diameter in the top lid. Later, a similar baffle was made of glass to enable researchers to observe the surface of the sample during the evaporative process.

## Evaporation Protocols

Initially, samples were shaken and then poured directly into a tared dish on the balance. A timer

was started, the baffle set in place, and an initial weight reading taken as quickly as possible. The normal pattern of evaporation for samples that did not contain wax was a rapid weight loss almost linear with time. The rate loss persisted until the sample had dried.

When wax was in the formulation, the initial period of rapid weight loss came to a fairly abrupt halt and was followed by a much slower rate of evaporation that remained generally constant until most of the methylene chloride had evaporated. Unfortunately, samples containing wax showed very poor reproductibility, with great variation in time to "shut down," the total weight loss prior to the shutdown, and in the rate of evaporation after shutdown. Variations between replicates of a factor of two, and sometimes substantially more, were not uncommon. Variations were also seen in the surface films formed by replicated solutions.

Researchers worked diligently to find the cause of variations between even essentially duplicate samples. Insights about the barrier-forming process gained from modifying evaporation tests were incorporated into test Protocol 1 and confirmed the importance of wax film in controlling the shutdown process. However, no real solution was achieved and imprecision was a continuing problem in assessing additive effectiveness.

### ■ Protocol 1

Samples were shaken and poured into a tared petri dish set on the Sartorius balance, the baffle was set in place, and weight loss was recorded until 10 minutes after shutdown. Next, the petri dish was covered for 10 minutes, then the cover was removed and weight loss recorded again. The later result (corrected for elapsed time) was taken as the rate of evaporation.

### ■ Protocol 2

At higher concentrations of wax or as more effective additives were studied, Protocol 1 became prohibitively slow. To increase productivity, a number of chimneys were constructed so 14 samples could be monitored simultaneously. Instead of continuously recording weight loss, samples were weighed at 15-minute intervals for two hours or more (if necessary) to achieve a total weight loss of at least 0.1 gram.

Replicate samples showed no consistent variation with their position in the hood. Replication was poorer than in Protocol 1 but still better than experienced in the early stages of the project for samples with lower evaporative losses.

## Strippability Testing

Stripping evaluations on prepared test panels were performed according to spot tests described in Robert Rodale's article (*New Shelter*, July/August 1983) on alkyd and urethane enamels.

Five mL of stripper was placed on a test panel, covered with a watch glass, and allowed to stand 20 minutes before a single pass scrape was made to remove loosened paint and stripper. Stripped spots were evaluated visually, and the color of the layer remaining was reported. In cases where the paint was stripped to the primer, an estimate of the primer area was reported. In addition, the degree of primer showing was determined by using a wire grid (80 units per square inch) and basing the relative percentage of primer showing on the relative percentage of grid openings that showed primer.

Direct comparison of results from the visual and grid methods showed a less than 5 percent variation. Resulting data showed a similar variation.

## Test Panels

The panels were made from 6-by-12-inch pine boards coated with four layers of either a good quality alkyd enamel in one series or four layers of a good quality commercial urethane enamel in a second series. Each layer of paint was a different color; the base primer coat was white. This made the number of layers removed readily apparent.

Several approaches were used to condition the test panels. For one set, each layer of paint was air dried prior to applying a subsequent layer. The painted panel was then placed in a forced-air oven at 110°C for 24 hours. A second set of panels was prepared by successively air drying (24 hours) and baking each applied layer overnight. For a third set, each paint layer was air dried and the painted panels were "aged" at room temperature for 10 weeks before being used.

## Results and Discussion

### The Experimental Matrix

The goal of the research was to develop a matrix of data that detailed information on the evaporation rate of methylene chloride in increasingly complex mixtures of components—methylene chloride, waxes and/or oils, thickening or gelling agents, lower alcohols (methanol), and toluene—that are

frequently found in commercial paint strippers. The matrix was then expanded to include additives that might reduce methylene chloride's evaporation rate.

The successive levels of the experimental matrix, in order of increasing complexity, were as follows:

- Methylene chloride
- Methylene chloride, wax
- Methylene chloride, wax, gelling agent
- Methylene chloride, wax, gelling agent, methanol
- Methylene chloride, wax, gelling agent, methanol, toluene.

In addition to the main branch of the matrix, studies were also conducted on the following mixtures that did not include wax:

- Methylene chloride, gelling agent
- Methylene chloride, methanol
- Methylene chloride, gelling agent, methanol.

At each matrix level, additives were incorporated into the formulation to determine their impact on evaporation rate. The additives studied at University of Missouri-Rolla fell into four general groups: five-membered ring, heterocyclic compounds; nonionic, surface-active chemicals; highly oxygenated, simple organic compounds; and a miscellaneous group of chemicals that were tried mostly on an exploratory basis.

### Methylene Chloride Studies

Much of the initial effort centered on developing weight-loss protocols. The weight-loss studies were run as part of the overall data gathering effort on the first levels of the experimental matrix. Measured evaporation rates for methylene chloride alone were generally fairly uniform until dryness for any given sample. A number of studies were done in which the effect of a baffle, cover, position within the fume hood, and other operational factors were evaluated. Overall, the reproducibility for methylene chloride alone was fairly good. Actual results from a variety of test situations generally fell within 26 to 31 mg/min/in<sup>2</sup>. The overall average (Table 1) was 29.1 mg/min/in<sup>2</sup>.

**Table 1.—Methylene chloride, wax solutions.**

SOLN. NO.	COMPOSITION	WT %	EVAP. RATE MG/MIN/IN <sup>2</sup>	NO. OF TESTS
1	Methylene chloride		29.1	14
2	Methylene chloride + hexadecane	0.4-12	26.3	3
3A	Methylene chloride + wax	0.5	1.8	20
3B	+ wax	1.0	2.2	11
3C	+ wax	1.5	0.4	1
	Average		1.9	32
4A	Methylene chloride, slack wax + wax	0.5		
	+ hexadecane	12.0	0.5	1
4B	+ wax	1.0		
	+ hexadecane	12.0	1.6	13
4C	+ wax	1.0		
	+ hexadecane	8.0	1.7	2
4D	+ wax	1.5		
	+ hexadecane	8.0	1.2	1
	Average		1.5	17

**Methylene Chloride—Wax**

Samples containing wax exhibited a more complex evaporation rate curve. There was initial shutdown period prior to formation of the wax barrier where the evaporation roughly approximated that of methylene chloride. After the wax barrier had formed, a substantially lower evaporation rate (steady state rate) was observed. Again, this evaporation rate usually persisted for a substantial period of time.

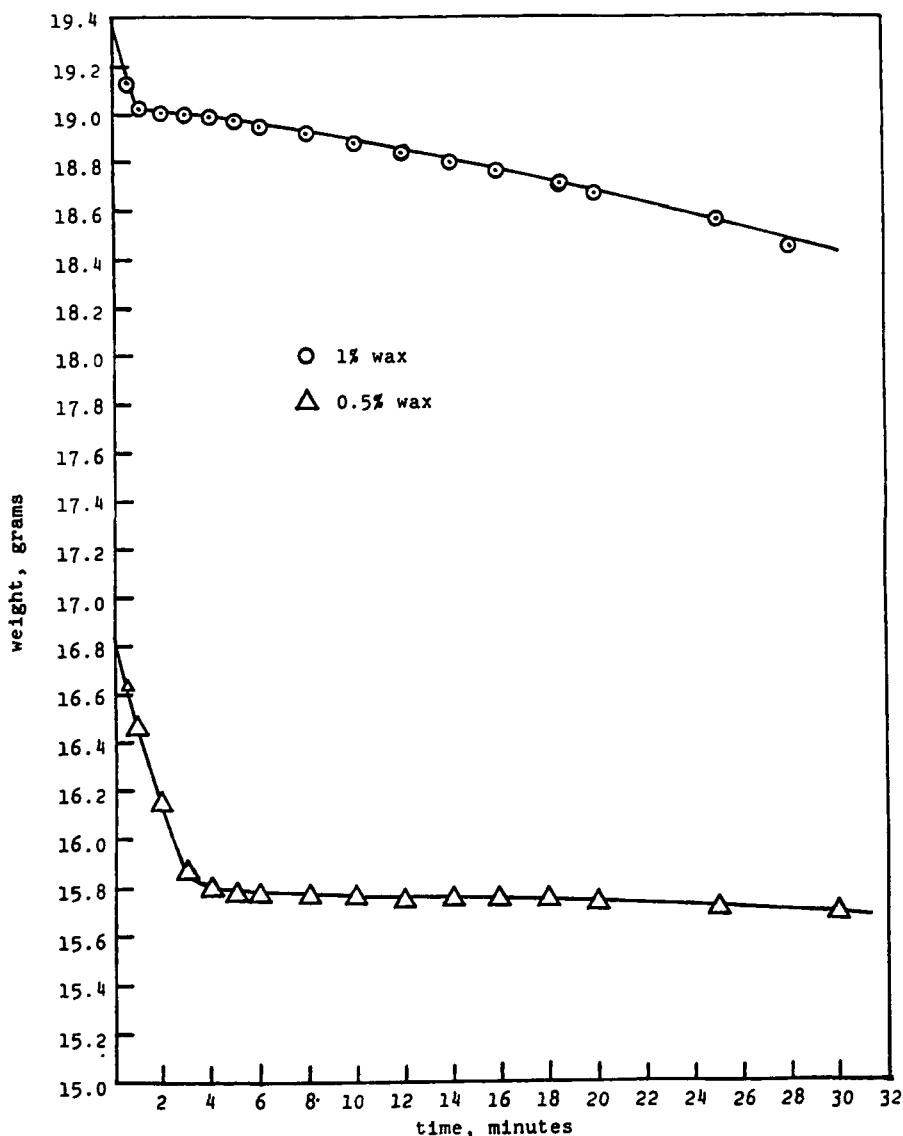
However, reproducibility of evaporation rate measurements in systems containing wax was quickly found to be problem. Reproducibility was a problem not only for the steady state rate measurements but also for the length of time prior to shutdown. In an attempt to overcome this problem, researchers tried a considerable number of weight-loss protocols. Replicate samples from the same master solution could (at times) exhibit evaporation rates that differed by a factor of 2 to 10. Unfortunately, no simple cause (or, in turn, solution) was found for the lack of reproducibility.

Increased replication did help in developing a useful database. The overall experimental strategy, as noted previously, centered on measuring the effect of individual components or additives on the evaporation rate. Within the

framework of the experimental matrix, a considerable number of individual experiments was designed to illustrate the impact of small changes in concentration of either additives or components. Often these experiments seemed to substantiate the theory that changes in concentration affected the evaporation rate.

Sometimes a greater than usual spread in results brought into question whether a difference in evaporation rate was associated with the variable being tested. Rather than try to differentiate or explain the differences in second order effects as being associated with relatively minor changes in concentration, the focus of this report was kept on the broader concepts: between elements of the matrix or “with versus without” comparisons for additives.

A wax level of 0.5 percent by weight seems to be about as effective (Table 1) as 1.0 percent by weight in reducing the evaporation rate. The single data point for the 1.5 percent solution needs more replication. However, Figure 1 shows the shut-



**Figure 1.—Evaporation rate—methylene chloride, wax solutions.**

down period was about one-third less with a 1.0 percent wax solution than with a 0.5 percent solution.

An attempt was made to see whether wax type affects barrier quality. A highly refined paraffinic wax and the so-called "slack" wax are used in commercial formulations; both are similar in that they are composed of long-chained paraffinic hydrocarbons. However, slack wax consists of a broader molecular weight range, and some of the hydrocarbons present are normally liquid at room temperature.

Slack wax was simulated in these studies by using a mixture of paraffinic wax and hexadecane. The latter was chosen to represent the liquid fraction in slack wax because it is essentially non-volatile. Hexadecane did not contribute much to the solubilization of wax in these predominantly methylene chloride solutions as the wax-hexadecane solutions are normally cloudy.

The overall evaporation rate averages for paraffinic wax and slack wax were 1.9 and 1.5 mg/min/in<sup>2</sup>, respectively (Table 1). While close, the lower numbers for cloudy hexadecane solutions suggest that the closer wax is to its saturation point in a formulation, the more readily the barrier will form and its effectiveness improve. The evaporation rate for methylene chloride hexadecane solutions (Table 1) were within the range seen for methylene chloride alone.

A number of additional experiments were run (Table 2) that focused solely on components' effect on the evaporation rate. Evaporation rate data are shown for:

- Methylene chloride alone,
- Methylene chloride in binary mixtures with methanol or a gelling agent, and

Table 2.—Effect of wax in simple mixtures.

SOLN. NO.	COMPOSITION	WT %	EVAP. RATE MG/MIN/IN <sup>2</sup>	NO. OF TESTS
1	Methylene chloride		29.1	14
2	Methylene chloride + wax	0.5	1.9	32
3	Methylene chloride + methanol	0.7–4.0	25.3	3
4	Methylene chloride + methanol + wax	1.0–5.2 0.5–1.0	1.4	12
5	Methylene chloride + gelling agent [S23]	1.0	22.0	2
6	Methylene chloride + gelling agent [S23] + wax	1.0 0.5–1.0	1.3	4
7	Methylene chloride + gelling agent [S23] + methanol	1.0 4.0	21.1	4
8	Methylene chloride + gelling agent [S23] + methanol + wax	1.0 2.0–4.0 0.4–1.0	0.46	22

- A ternary mixture of methylene chloride, methanol, and a gelling agent.

Data are also presented for each solution where wax has been added as an additional component that suggest mixing methanol and a gelling agent affects (to a modest extent) the evaporation rate of methylene chloride solutions that do not contain wax. Obviously, from the data (Table 2), wax is the key element in establishing the evaporation rate, which is well understood within the paint stripping industry.

Interestingly, the contribution of methanol and gelling agent seems to be observable even in more complex solutions that contain wax. In methylene chloride-wax solutions, methanol or the gelling agent (S23) seem to contribute roughly equally to reducing the evaporation rate. Their effectiveness seems to be additive as the combination of gelling agent, wax, and methanol drops the evaporation rate another 0.9 mg/min/in<sup>2</sup>.

## Surfactant Studies

The first class of additives studied were nonionic, surface-active materials; included were a fluorinated compound and various nonionic ethers and esters (Table 3). Some of these materials, such as the sucrose esters, were recognized by Cox in a British patent No. 1,023,213 as being particularly effective in reducing the evaporation rate for volatile organic compounds. Most of the surfactants seemed to have some effect (Table 4) in lowering evaporation as the observed rates generally fell in the 15 to 24 mg/min/in<sup>2</sup> range.

Of the materials studied (Table 4), only the mixed sucrose esters Croda F-50 and F-110 and sorbitan monostearate were effective in substantially reducing the evaporation rate of methylene chloride. Interestingly, only those sucrose esters containing monostearate were effective in reducing evaporation rate. Likewise, monostearate was effective while neither the monopalmitate or monooleate seemed to impact the evaporation significantly. The monostearate appeared to form platelets on the surface.

These results differ somewhat from the observations made by Cox for benzene-surfactant solutions. The evaporation rate for methylene chloride-Croda F-50 was one of the lowest recorded in the early stages of this study.

An additional set of experiments were run with methylene chloride and some of the surfactants. However, these tests (Table 5) also included 0.5 percent wax. The average evaporation rate for

**Table 3.—Surfactants.**

ZONYL FSN	E. I. DU PONT & CO	NONIONIC FLUORO-CHEMICAL SURFACTANT
Crodesta F-10	Croda Inc.	Sucrose distearate
Crodesta F-50	Croda Inc.	71/29 mixture of sucrose di- and mono-stearate
Crodesta F-110	Croda Inc.	48/52 mixture of sucrose di- and mono-stearate
Alkamuls SMO	Alkaril Chemicals	Sorbitan monooleate
Alkamide L7DE	Alkaril Chemicals	Lauric-myristic monoethanolamide
Alkamide 1002	Alkaril Chemicals	Coconut alkanolamide
Arlacel 20	ICI Americas Inc.	Sorbitan monolaurate
Arlacel 40	ICI Americas Inc.	Sorbitan monopalmitate
Arlacel 60	ICI Americas Inc.	Sorbitan monostearate
Arlacel 80	ICI Americas Inc.	Sorbitan monooleate
Brij 30	ICI Americas Inc.	Polyoxyethylene (4) lauryl ether
Brij 35	ICI Americas Inc.	Polyoxyethylene (23) lauryl ether

**Table 4.—Methylene chloride: surfactant studies.**

SOLN. NO.	COMPOSITION	WT %	EVAP. RATE MG/MIN/IN <sup>2</sup>	NO. OF TESTS
1	Methylene chloride Methylene chloride + surfactant additive		29.1	14
2A	Zonyl FSN 100	3-12	19.9	4
2B	Crodesta F10	1.0	20.2	1
2C	Crodesta F50	1.0	0.4	4
2D	Crodesta F110	1.0	1.0	4
2E	Alkaril A1002	1.0	23.8	1
2F	Alkaril AL7DE	1.0	24.5	1
2G	Alkaril SMO	1.0	23.7	1
2H	Arlacel 20	1.0	15.4	1
2I	Arlacel 40	1.0	23.3	1
2J	Arlacel 60	1.0	0.1	1
2K	Arlacel 80	1.0	22.8	1

wax-methylene chloride was 1.9 mg/min/in<sup>2</sup>. Neither of the two Croda sucrose derivatives seemed to be beneficial in that the evaporation rate for these materials in wax-methylene chloride solution was higher than the baseline rate.

**Table 5.—Methylene chloride, wax: surfactant studies.**

SOLN. NO.	COMPOSITION	WT %	EVAP. RATE MG/MIN/IN <sup>2</sup>	NO. OF TESTS
1	Methylene chloride + wax Methylene chloride + wax + surfactant additive	0.5 0.5	1.9	32
2A	Zonyl FSN 100	1-4	15.2	3
2B	Crodesta F50	1.0	4.3	2
2C	Crodesta F110	1.0	3.4	2
2D	Arlacel 40	1.0	1.1	1
2E	Arlacel 60	1.0	0.7	1

Zonyl FSN-100 seemed to be very disruptive to the barrier. One can speculate that the fluorocarbon caused some "wetting" problems that resulted in poor adhesion between wax platelets.

Of the two sorbitan derivations tested, Arlacel 40 was much more effective than when present as the sole additive in methylene chloride—1.1 versus 23.3 mg/min/in<sup>2</sup>. On the other hand, Arlacel 60, which was effective in methylene chloride alone, with an evaporation rate of 0.1 mg/min/in<sup>2</sup>, seemed to be less effective in the presence of

wax—0.7 mg/min/in<sup>2</sup>. The evaporation rate for Aracel 60-methylene chloride-wax solution was still lower than that shown by the methylene chloride-wax baseline measurements.

The data suggest that the influence of large surfactant molecules on the wax barrier can be significant both in a positive or negative direction in relatively simple solutions. They also indicate that the wax barrier formation takes place within a small region near the surface and is influenced by the concentration of wax and changing solubility limits for wax in this region. The ability of these large molecules to participate in barrier formation in more complex solutions containing gelling agents is questionable. The focus of research efforts at the University of Missouri-Rolla therefore was shifted to smaller, more mobile molecules.

### Additive Selection

In selecting additives that might desolubilize wax and thus decrease the evaporation rate, attention was next given to compounds that contained a high concentration of polar groups or groups that might be capable of forming hydrogen bonds with methylene chloride. The primary candidates were alcohols, ethers, esters, and amines. Other than the shorter alcohols and amines, these compounds are miscible with liquid-saturated

hydrocarbons and are not expected to be very effective at desolubilizing wax.

The five-membered ring heterocyclic derivatives were the first generation of the additives that were studied. Prior studies of simple heterocyclic compounds containing a carbonyl functionality had shown that they were capable of very strong intermolecular interactions, perhaps stronger than conventional hydrogen bonding, as evidenced by boiling points in excess of 200°C. Included in this group were  $\gamma$ -butyrolactone, 2-pyrrolidone, *N*-methyl pyrrolidone, and related compounds. After this study had been underway for some time, a patent was issued to Dow Chemical detailing the use of propylene carbonate as an additive to reduce evaporation rate in paint stripper formulations. For comparison studies, propylene carbonate was included in the subsequent test programs.

During the course of these studies, the limited miscibility of methylene chloride and glycerine suggested that glycerine might offer some unique opportunities as an additive. Glycerine, whose density ranges between that of wax and methylene chloride, might also come out of a solution near the surface and provide a unique layer to complement the wax barrier. These considerations lead to the inclusion of glycerine and the related ethylene glycol as the second generation of additives in this research effort. The effectiveness of glycerine also led to studies with various polyethylene glycols of different molecular weights as well as a polyethylene glycol-methyl ether. Finally, some experiments were run on amine additives. The polyglycol and amine additives were considered the third generation of additives.

### Methylene Chloride, Wax: Additive Studies

The simple five-membered ring heterocycles had limited influence on the evaporation rate for methylene chloride (Table 6). This was also true in more complex solutions containing methanol and/or a gelling agent (Table 7). Of the materials studied, only propylene carbonate seemed to reduce the evaporation rate in methylene chloride solutions without wax that contained a gelling agent and methanol.

Table 6.—Methylene chloride: additive studies (no wax).

SOLN. NO.	COMPOSITION	WT %	EVAP. RATE MG/MIN/IN <sup>2</sup>	NO. OF TESTS
1	Methylene chloride		29.1	14
2	Methylene chloride + $\gamma$ -decanolactone	1.0	25.1	2
3	Methylene chloride + $\delta$ -decanolactone	1.0	29.8	2

Table 7.—Methylene chloride, gelling agent, methanol: additive studies (no wax).

SOLN. NO.	COMPOSITION	WT %	EVAP. RATE MG/MIN/IN <sup>2</sup>	NO. OF TESTS
1	Methylene chloride		21.1	4
	+ gelling agent [S23]	1.0		
	+ methanol	4.0		
	Methylene chloride			
2A	+ gelling agent [S23]	1.0	20.9	2
	+ methanol	4.0		
	+ heterocyclic additive			
	<i>N</i> -methyl pyrrolidone	1.0		
2B	Butyrolactone	1.0	21.8	2
2C	Propylene carbonate	1.0	16.5	2
3	Methylene chloride		18.6	2
	+ gelling agent [S23]	1.0		
	+ methanol	4.0		
	+ glycerine	1.0		

However, a wide range of five-membered heterocyclic ring derivatives appear (Table 8) to enhance the effectiveness of the wax barrier in relatively simple methylene chloride-wax solutions. Although replication is insufficient, the most effective additive was  $\gamma$ -decanolactone. *N*-methyl pyrrolidone, butyrolactone, and propylene carbonate were equally as effective. All of these additives compared (Table 8) favorably against methanol in reducing the overall evaporation rate. The average evaporation rate for this class of materials was 1.2 mg/min/in<sup>2</sup> as compared to the baseline without additives of 1.9 mg/min/in<sup>2</sup>. Tetramethylene sulfone, succinimide, and glycol sulfite were considered to be marginal in their effectiveness and not studied further.

Table 8.—Methylene chloride, wax: additive studies.

SOLN. NO.	COMPOSITION	WT %	EVAP. RATE MG/MIN/IN <sup>2</sup>	NO. OF TESTS
1	Methylene chloride		1.9	32
	+ wax	0.5-1.5		
	Methylene chloride			
2A	+ wax	0.5-1.5	1.0	6
	+ heterocyclic additive			
	<i>N</i> -methyl pyrrolidone	2-5		
2B	Butyrolactone	2-5	1.0	6
2C	Propylene carbonate	2-6	1.0	6
2D	2-pyrrolidone	2-5	1.1	4
2E	$\gamma$ -decanolactone	2.0	0.6	1
2F	$\delta$ -decanolactone	2.0	1.6	2
2G	Tetramethylene sulfone	2.0	1.6	2
2H	Succinimide	2.0	1.6	2
2I	Glycol sulfite	2.0	2.0	2
	Average		1.2	31
3	Methylene chloride		1.4	12
	+ wax	0.5-1.5		
	+ methanol	1-5		

Some limited studies were done to see if paraffinic versus slack wax had an impact on the evaluation of the additives. None of the five-membered ring compounds fared as well (Table 9) in solutions containing 8 to 12 percent of hexadecane. The issue appears to be one of

solubility, with the hexadecane undoing (to some extent) the polar influence of the heterocyclic derivatives. This issue will be taken up again when the experimental matrix is expanded to include toluene.

**Table 9.—Methylene chloride, slack wax: additive studies.**

SOLN. NO.	COMPOSITION	WT %	EVAP. RATE MG/MIN/IN <sup>2</sup>	NO. OF TESTS
1	Methylene chloride			
	+ wax	0.5–1.5		
	+ hexadecane	8–12	1.5	17
	Methylene chloride			
	+ wax	0.5–1.5		
	+ hexadecane	8–12		
	+ heterocyclic additive			
	Average		1.7	16
2A	N-methyl pyrrolidone	2–4	1.6	4
2B	Butyrolactone	2–4	1.4	4
2C	Propylene carbonate	2–4	1.8	4
2D	2-pyrrolidone	2–4	2.1	4

### Experimental Matrix Studies

The next level of experimental matrix to be studied consisted of methylene chloride solutions containing wax and a gelling agent, hydroxypropyl cellulose (S23). In these studies, the level of S23 was kept constant at 1 percent while the wax concentration ranged from 0.5 to 1.5 percent. The baseline evaporation rate for the three-component system was 1.26 mg/min/in<sup>2</sup> (Table 10). All of the five-member heterocyclic derivatives studied (Table 10) resulted in a substantial decrease in evaporation rate when incorporated into the formulation at a level of 1.0 weight percent. In this phase of the study, N-methyl pyrrolidone and  $\gamma$ -butyrolactone gave the best results.

**Table 10.—Methylene chloride, wax, gelling agents, additives.**

SOLN. NO.	COMPOSITION	WT %	EVAP. RATE MG/MIN/IN <sup>2</sup>	NO. OF TESTS	
1	Methylene chloride				
	+ wax	0.5–1.0			
	+ gelling agent [S23]	1.0	1.26	4	
	Methylene chloride				
	+ wax	1.0–2.0			
	+ gelling agent [S23]	1.0			
	+ heterocyclic additive				
	Average		0.47	10	
2A	N-methyl pyrrolidone	1.0	0.38	2	
2B	Butyrolactone	1.0	0.30	2	
2C	Propylene carbonate	1.0	0.45	2	
2D	$\gamma$ -decanolactone	1.0	0.48	2	
2E	$\delta$ -decanolactone	1.0	0.75	2	
	Average		0.47	10	
	Methylene chloride				
	+ wax	1.0–2.0			
	+ gelling agent [S23]	1.0			
	+ polyhydroxy additive				
	Average		0.11	11	
	3A	Glycerine	1.0	0.03	3
	3B	Ethylene glycol	1.0	0.09	14

Results for the second generation additives were even better. Solutions containing either glycerine or ethylene glycol exhibited an order of magnitude reduction in evaporation rate. While the complexity of these solutions is relatively modest as compared to commercial formulations currently being sold by paint stripper manufacturers, these results were once considered very promising and contributed to the continuation of the sponsored research project for another year.

The experimental program moved on to the next matrix level with the inclusion of methanol in the formulation. The only component that was held constant in concentration was the gelling agent (S23), at 1 weight percent. Wax was varied from 0.5 to a high of 2.0 percent in one experiment, while methanol ranged from 2.0 to 4.0 percent. The baseline evaporation rate was determined to be 0.46 mg/min/in<sup>2</sup> (Table 11) from a fairly large number of experimental tests. As a whole, the five-membered ring heterocyclic compounds still appeared to contribute to a reduction in the evaporation rate with the overall average being 0.30 mg/min/in<sup>2</sup>.

**Table 11.—Methylene chloride, wax, gelling agents, methanol, additives.**

SOLN. NO.	COMPOSITION	WT %	EVAP. RATE MG/MIN/IN <sup>2</sup>	NO. OF TESTS	
1	Methylene chloride				
	+ wax	0.4–1.0			
	+ gelling agent [S23]	1.0	0.46	22	
	+ methanol	2.0–4.0			
	Methylene chloride				
	+ wax	0.5–2.0			
	+ gelling agent [S23]	1.0			
	+ methanol	2.0–4.0			
	+ heterocyclic additive				
	Average		0.30	16	
	2A	N-methyl pyrrolidone	1.0	0.29	4
	2B	Butyrolactone	1.0	0.25	4
2C	Propylene carbonate	1.0	0.24	4	
2D	$\gamma$ -decanolactone	1.0	0.35	2	
2E	$\delta$ -decanolactone	1.0	0.19	2	
	Average		0.30	16	
	Methylene chloride				
	+ wax	0.5–2.0			
	+ gelling agent [S23]	1.0			
	+ methanol	2.0–4.0			
	+ polyhydroxy additive				
	Average		0.16	32	
	3A	Glycerine	1–4	0.13	17
3B	Ethylene glycol	1–4	0.20	15	
	Average		0.16	32	
	Methylene chloride				
	+ wax	0.5–2.0			
	+ gelling agent [S23]	1.0			
	+ methanol	2.0–4.0			
	+ polyglycol additive				
	Average		0.13	12	
	4A	BRIJ 30	1.0	0.16	4
4B	BRIJ 35	1.0	0.14	2	
4C	PEG 140	1.0	0.15	2	
4D	PEG 208	1.0	0.07	2	
4E	PEGME	1.0	0.12	2	
	Average		0.13	12	

In this series of tests,  $\delta$ -decanolactone appeared to be the best performer. Both of the second generation additives continued to look good.

Again, for a fairly large number of tests, glycerine solutions showed an average evaporation rate of 0.13 mg/min/in<sup>2</sup>, while the corresponding number for ethylene glycol was 0.20 mg/min/in<sup>2</sup>. Some limited testing with polyglycol derivatives is also presented (Table 11) and, in many respects, the materials also look promising in these rather elementary formulations.

For both the five-membered ring heterocycles and the polyhydroxy compounds of the second generation, the effect of the additives was less at this matrix level (Table 11)—as compared to the prior level (Table 10).

Possibly this trend reflects the contribution that methanol makes to desolubilization of the wax without the presence of any additional additives. The observed difference between the so-called first and second generation additives may be a result of the "liquid" barrier. These results suggest that additives such as the five-membered ring heterocycles, which seem to rely primarily on reducing the solubility of wax, will at best be only marginally effective in high "methanol" paint stripper formulations—that is, formulations with greater than 10 percent methanol.

The next matrix level studied in this laboratory program involved the addition of toluene to the formulation. While both toluene and methanol content were varied within limits, these experiments did feature fixed concentrations of wax and gelling agent at 1.0 weight percent. Toluene was included in the matrix because it has been found in commercial formulations and it represents a wax "solubilizer" as compared to methanol, which is believed to reduce the solubility of wax. The baseline evaporation rate developed for this five-component matrix was 0.41 mg/min/in<sup>2</sup> (Table 12) and differed only modestly from the baseline observed for solutions that did not contain toluene (Table 11). While the five-membered ring heterocyclic derivatives still showed some ability to reduce the evaporation rate, the gap with baseline results narrowed considerably (Table 12 versus Table 11). The effectiveness of glycerine was also less in solutions containing toluene; however, there was still a 50 percent reduction as compared (Table 12) to the baseline measurement.

Results for ethylene glycol solutions were expected as they exhibited highly elevated rates as compared to the baseline solutions. The reason for these results is unclear, although the trend agrees with the earlier slack-wax studies. Perhaps in the presence of wax solubilizers, higher additive levels

Table 12.—Methylene chloride, wax, gelling agents, methanol, toluene, additives.

SOLN. NO.	COMPOSITION	WT %	EVAP. RATE MG/MIN/IN <sup>2</sup>	NO. OF TESTS
1	Methylene chloride			33
	+ wax	1.0		
	+ gelling agent [S23]	1.0		
	+ methanol	2.0-4.0	0.41	
	+ toluene	0.0-2.0		
	Methylene chloride			
	+ wax	1.0		
	+ gelling agent [S23]	1.0		
	+ methanol	2.0-4.0		
	+ toluene	0.0-2.0		
	+ heterocyclic additive			
2A	<i>N</i> -methyl pyrrolidone	1-4	0.36	12
2B	Butyrolactone	1-4	0.39	10
2C	Propylene carbonate	1-4	0.38	12
	Average		0.38	16
	Methylene chloride			
	+ wax	1.0		
	+ gelling agent [S23]	1.0		
	+ methanol	2.0-4.0		
	+ toluene	0.0-2.0		
	+ polyhydroxy additive			
3A	Glycerine	1-4	0.22	14
3B	Ethylene glycol	1.0	3.83	2
	Average		0.67	16
	Methylene chloride			
	+ wax	1.0		
	+ gelling agent [S23]	1.0		
	+ methanol	2.0-4.0		
	+ toluene	0.0-2.0		
	+ polyamine additive			
4A	Triethanol amine	1-4	0.24	11
4B	Tetraethylenetetraamine	1-4	0.23	12
	Average		0.23	23

are needed to impact the evaporation rate. Yet, the baseline data do not suggest that toluene weakens the evaporation barrier.

Some additional experiments are reported on tests involving the use of polyfunctional amines as additives. While the data (Table 12) appear to be comparable to those recorded for glycerine solutions, other observations bring into question the use of amines in this application. Specifically, the solutions appeared to "salt-out" on standing. Speculation postulated that the amines catalyzed the hydrolysis or reacted with methylene chloride with the resultant formation of amine hydrochlorides. Since commercial formulations must exhibit long-term stability, no further studies were performed with amine additives.

### Thickening Agent Comparison

The final set of studies within the matrix involved a comparison of gelling agents. The thixotropic agent used in most of the laboratory studies was hydroxypropyl cellulose (S23). Comparative runs were made with another gelling agent, ethylcellulose (S105), both with and without glycerine. In

these experiments, comparisons were made both for methylene chloride/wax/gelling agent/methanol and methylene chloride/wax/gelling agent/methanol/toluene solutions.

For the purposes of this segment of the study, the data were combined (Table 13) without factoring in the presence or absence of toluene. In both comparisons, solutions containing the hydroxypropyl cellulose (S23) thickening agent exhibited lower evaporation rates than were seen for formulations containing ethylcellulose (S105). The effectiveness of glycerine as an additive was marginal in these experiments. A substantially better reduction was noted earlier (Table 12) with similar solutions.

Table 13.—Gelling agent studies.

SOLN. NO.	COMPOSITION	WT %	EVAP. RATE MG/MIN/IN <sup>2</sup>	NO. OF TESTS
1A	Methylene chloride			
	+ wax	1.0		
	+ gelling agent [S23]	1.0		
	+ methanol	1.0–2.0		
	+ toluene	0.0–2.0	0.46	8
1B	Methylene chloride			
	+ wax	1.0		
	+ gelling agent [S23]	1.0		
	+ methanol	1.0–2.0		
	+ toluene	0.0–2.0		
	+ glycerine	1.0–2.0	0.38	4
	Average		0.42	12
2A	Methylene chloride			
	+ wax	1.0		
	+ gelling agent [S105]	1.0		
	+ methanol	1.0–2.0		
	+ toluene	0.0–2.0	0.63	8
2B	Methylene chloride			
	+ wax	1.0		
	+ gelling agent [S105]	1.0		
	+ methanol	1.0–2.0		
	+ toluene	0.0–2.0		
	+ glycerine	1.0–2.0	0.56	4
	Average		0.61	12

### Commercial Formulations

The real test for any additive would be in its successful incorporation in a commercial stripper formulation. The program was not designed to develop a "commercial" formulation nor to break down the many possible combinations used today in commercial paint removing products. To gain an insight as to whether the additive concept could be employed commercially, glycerine was added to three formulations. As seen in the resultant data (Table 14), there is a substantial variation in the evaporation rates of the commercial stripping formulations. In one case (Formulation B), the addition of glycerine substantially increased the observed evaporation rate. However, Formulation B already exhibited an evaporation rate substantially higher than most of the "model" formula-

tions. Two other commercial products (A and C) exhibited low evaporation rates. Although the level of replication was insufficient to draw firm conclusions, there may have been some additional reduction of evaporation rate because of the addition of glycerine.

Table 14.—Commercial formulations.

SOLN. NO.	COMPOSITION	WT %	EVAP. RATE MG/MIN/IN <sup>2</sup>	NO. OF TESTS
1	Formulation A		0.08	2
2	Formulation A			
	+ glycerine	1.0	0.05	2
3	Formulation B		0.93	12
4	Formulation B			
	+ glycerine	1.0	2.72	2
5	Formulation C		0.07	10
6	Formulation C			
	+ glycerine	1.0	0.06	6

### Stripping Effectiveness

Some variations of cure conditions for test panels used in this study were noted previously. There was some concern whether differing conditioning protocols would significantly affect the outcome of the stripping tests. A series of test panels were tested for strippability by a commercial stripper. These test panels included:

- A one-year-old panel in which each layer was oven-baked for 24 hours before a subsequent layer was applied;
- An air-dried, 10-week-old test panel; and
- An oven-baked, 10-week-old panel in which each coating layer was air-dried for 24 hours before a subsequent layer was applied.

Stripping rates were determined for alkyd and urethane coatings, two ratings (Table 15) for each test. The first number represents a visual estimate of the percentage of white primer visible after the stripping solution was scraped from the surface. The second number represents an attempt at a more quantifiable estimate in which a wire grid (81 units per square inch) was placed over the test area and ratio grid units showing white to the total number of grid units in the stripped surface area was calculated. While the two results are comparable, the grid unit seems to result in a lower estimate of effectiveness. The mode of preparation for alkyd test panels seems to have minimal effect. Somewhat surprisingly, the urethane panels prepared by air drying between the application of each coating layer with subsequent oven-drying of panels were the most difficult to strip.

Stripper tests were also run for model formulations containing methanol and glycerine (Table

**Table 15.—Test panel conditioning: stripping tests.**

TEST PANEL CONDITIONING	ALKYD COATING	URETHANE COATING
	PERCENT PRIMER VISIBLE*	
Oven-baked, 1-yr. old	100 (96)	90 (90)
Air-dried, oven-baked, 10-weeks old	100 (98)	70 (65)
Air-dried, 10-weeks old	100 (95)	90 (88)

\*The first number of each pair is a visual estimate, while the second number is a calculated ratio from reading a grid.

16). The formulations tested consisted of methylene chloride, wax (1 percent), and thickening agent (1 percent S23), along with the specified levels of methanol and glycerine. These results suggest that glycerine can contribute to the effectiveness of the stripper. The ratio of glycerine relative to methanol is important; a 1 percent glycerine, 4 percent methanol formulation may be

**Table 16.—Stripping tests: methanol, glycerine formulations.**

METHANOL [PERCENT]	GLYCERINE [PERCENT]	ALKYD COATING [PERCENT PRIMER VISIBLE]	URETHANE COATING [PERCENT PRIMER VISIBLE]
4.0	0.0	50	80
4.0	1.0	99	(a)
4.0	2.0	90	40
4.0	4.0	95	50
2.0	2.0	100	100
2.0	4.0	85	20

(a) wood grain visible

optimum. As expected, alkyd test panels stripped easier than urethane coatings.

A more extensive series of formulations containing five-membered ring heterocyclic compounds and glycerine were tested next for their strippability. The formulations that were chosen exhibited an evaporation rate below 0.20 mg/min/in<sup>2</sup>. These test formulations (Table 17) included wax (1 percent), thickening agent (1 percent S23), and specified levels of methanol and toluene. Unlike the prior study, results for none of the additives were as good as the baseline results. Again, these formulations included toluene, which was shown to negatively affect the additives' ability to reduce the evaporation rate.

## Conclusions and Recommendations

The testing program included alcohols (wax desolubilizers) and hydrocarbons (wax solubilizers). Many commercial formulations also include activators and surfactants to enhance the onset of the stripping process and aid in removing stripping residues. Extension of the matrix to include activators and surfactants would be valuable.

The experimental data indicate the effectiveness of additives is moderated as the formulations become more complex. Each component in the formulation can affect the effectiveness of the ad-

**Table 17.—Stripping tests: methanol, toluene formulations.**

METHANOL [PERCENT]	TOLUENE [PERCENT]	ADDITIVE	ALKYD COATING [PERCENT PRIMER VISIBLE]	URETHANE COATING [PERCENT PRIMER VISIBLE]
4.0	1.0	0.0	70	60
4.0	2.0	0.0	80	90
2.0	1.0	0.0	80	80
2.0	2.0	0.0	30	50
<b>Glycerine</b>				
4.0	1.0	1.0	75	60
4.0	2.0	1.0	80	70
2.0	1.0	1.0	70	50
2.0	2.0	1.0	20	30
<b>N-methyl pyrrolidone</b>				
4.0	1.0	1.0	70	50
4.0	2.0	1.0	70	80
2.0	2.0	1.0	30	20
<b>γ-butyrolactone</b>				
4.0	1.0	1.0	50	10
4.0	2.0	1.0	70	60
2.0	1.0	1.0	80	50
2.0	2.0	1.0	0	60
<b>Propylene carbonate</b>				
4.0	1.0	1.0	80	60
4.0	2.0	1.0	70	70
2.0	1.0	1.0	60	80
2.0	2.0	1.0	5	40

ditive. One of the critical factors is the balance between polar and nonpolar solvent functions within the formulation. Taken in total, the work strongly suggests that an additive approach can contribute to a reduction in evaporation rate.

Of the additives studied, glycerine seems unique in that it may, because of its limited solubility in methylene chloride, provide a liquid barrier to complement the more usual wax barrier. The other five-membered ring heterocyclic compounds studied also appear to have some potential in reducing the evaporation rate of methylene chloride. Their performance should be equivalent to that provided by propylene carbonate, which

has been patented by Dow Chemical Company for this end-use application. Of these materials, *N*-methyl pyrrolidone seems to have the most potential.

Since there is considerable variety in formulations used in paint remover products in the United States, it is apparent that these additives must be tested within the framework of the individual manufacturer's formulations. To this end, Vulcan Chemicals and Occidental Chemical have entered into an agreement with the University of Missouri to facilitate the evaluation of these additives by paint remover manufacturers.

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# HOUSEHOLD & COMMERCIAL PAINT STRIPPING

## Questions & Discussion

**D**iscussion in the Household and Commercial sessions focused on consumer sophistication in using paint strippers, the safety of substitute strippers, and methods of pollution prevention and exposure control. Discussion in the first breakout session focused on consumer end-uses of strippers and the extent to which consumers are aware of the types of coatings that they are removing. The discussion was prompted by a suggestion that different stripper formulations could be marketed for the removal of different coatings. Participants noted that the primary obstacle to this is limited consumer knowledge of the coating being removed. In addition, the area or item to be stripped is often covered by several layers of possibly different coatings, making it impossible for even the most informed consumer to determine the suitability of a particular stripper.

Questions following the substitute formulation presentations on Tuesday afternoon were aimed at the appropriateness of labelling any paint stripper as "safe." Sandra Eberle of the CPSC pointed out that, in general, disclaimers are not permissible in labelling under the Federal Hazard-

ous Substances Act (FHSA) and that there is no official definition of "non-toxic." The discussion pointed to a general dissatisfaction with the amount of information available on the safety of substitute paint strippers. Other comments were made about rinsing the substrate with alcohol when applying NMP-based strippers. Gerald L. Bixenman noted that there was a contradiction in marketing NMP products as non-flammable while simultaneously recommending the use of a highly flammable alcohol rinse with the stripper.

Wednesday's first presentations in the household/commercial session was followed by a discussion of an integrated approach to pollution prevention. Some proponents of methylene chloride-based strippers maintain that little waste is generated in using these strippers since methylene chloride evaporates, leaving only dried paint to be landfilled. Ed Baird of Wilson Imperial pointed out that evaporated methylene chloride should not be thought of as disappearing, since it remains in the air. Janet Hickman of Dow Chemical added that the ideal control system would be one in which the stripping material is recovered and prevented from going into the environment.

Also in this session, trends in coating and stripping were discussed. Nancy Lindquist, a professional finisher, remarked that there is a trend towards tougher and tougher coatings and a concurrent trend towards weaker and more benign strippers. This poses challenges to the stripper industry, particularly in the removal of polyurethane coatings.

In the final session, questions predominantly concerned Cheryl Fairfield's presentation of engineering controls for furniture stripping. Several people expressed interest in the details of the

NIOSH study and the costs of implementing the controls described in the study. Cheryl Fairfield said that the details of the study will be published and a pamphlet will be produced for furniture strippers. Mechanical barriers to exposure control were also discussed. Gordon Bock of the *Old-House Journal* asked if anyone had experimented with mechanical barriers to control evaporation. Michael Clarkson said that this type of system had been tried in the UK, but that consumers had some difficulty using it.

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# **CLOSING SESSION**

**Chair: Mary Ellen Weber**  
*Director, Economics and Technology Division*  
*Office of Toxic Substances*  
*U.S. Environmental Protection Agency*

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# Panel Reports: Summary of Findings

## **Christine Whittaker**

*Office of Risk Reduction Technology  
Health Standards Division  
U.S. Occupational Safety and Health Administration*

## **James Gideon**

*Division of Physical Sciences and Engineering  
National Institute for Occupational Safety and Health  
Washington, D.C.*

## **Sandra Eberle**

*Program Management and Budget  
U.S. Consumer Product Safety Commission  
Washington, D.C.*

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## **Original Equipment Manufacturing**

### **■ Christine Whittaker**

To summarize the major themes that were addressed in our panel sessions, I would like to begin by considering what would be the characteristics of a perfect paint stripper. Based on the applications described for OEM paint stripping, such a substance or process would have good stripping effectiveness on a wide variety of coatings; it would be both fast and complete in its stripping action; it would be low cost, have low toxicity, and be effective on both new and old paint films and coatings; it would have no odor and would be completely non-flammable. Unfortunately, there is no perfect paint stripper. The best paint stripping product or process will be different for each application. All of the alternatives discussed in the OEM sessions have trade-offs with respect to applicability, effectiveness, and cost. The goal in selecting the correct process is to optimize the formulation or technique for the requirements of particular paint stripping applications.

We can review several major themes that were discussed in the OEM panels.

No one single method of stripping paint is ideal for every paint removal application.

For example, cured paints pose very different technical requirements for effective removal than do uncured paints. Combinations of several methods (hybrid techniques) for effective removal are sometimes much more efficient with respect to both cost and performance than a single method alone. We heard about the combined use of chemical strippers and plastic media blasting, very cold liquid nitrogen accompanied by plastic media blasting; sponge blasting with chemical stripper; and the use of coatings and water rinses.

For substitute chemical solvent formulations, we can conclude that there are some promising substitutes, including NMP, though at this time they may be quite expensive. The challenge for chemical formulations is to devise a formulation which reduces cost and still maintains stripping effectiveness. For mechanical strippers, there are some limits to the processes' applicability. These limitations are a function of both substrate composition and the type of coating to be removed. This may, of course, be equally true for chemical strippers. For example, we heard that Ultra High Pressure Water may best be used on steel, iron, and equivalent substrates; cryogenic systems work best on thicker coatings, and may not be appropriate for some soft substrates.

Other stripping methods described in the OEM sessions included the use of barrier coatings—protective covers—that are water rinsible. These

coatings are particularly suitable for use to remove overspray in paint booths.

In addition to stripping effectiveness, a number of other issues are important to the evaluation of paint stripping processes. The time required for stripping, for example, is an important consideration. Substitute stripping methods, although not as fast as methylene chloride, seem to be effective within an acceptable time period. Paint stripping methods vary widely with respect to type and extent of costs incurred. Chemical solvents can be costly to purchase on a regular basis, while mechanical strippers may have a large capital outlay to finance equipment purchase. Recycling of methylene chloride strippers may reduce environmental releases and improve cost profile.

Concerning toxicity, one interesting address highlighted several approaches to reduce volatile organic releases that can be used without incurring appreciable added costs or process changes. Among these were a reduction in volume of stripper used, which may be accomplished through a change in the method of stripper application. For example, thixotropic strippers may adhere to surfaces better, or the use of spray instead of mop and bucket may provide more efficient coverage for certain paint clean-up operations. Finally, in some cases, it may be appropriate to replace some solvent use with water-based barrier coatings.

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## Maintenance Paint Stripping

### ■ James Gideon

The objective of paint stripping is to remove the coating while leaving the substrate intact. There are a series of constraints in this process, including air and water pollution, generation of solid waste, protection of workers, and cost. Paint removal involves an inherent contradiction because coatings are getting tougher while substrates are often becoming thinner or use more exotic materials, such as fiber-reinforced epoxy. A safe removal method must have a fundamentally different effect on the coating than on the substrate.

Paint can be removed in several ways. The time-honored method is to degrade the coating by using a solvent such as methylene chloride, a traditional baseline stripper. Our session only touched on the other solvents; primarily, we discussed a variety of mechanical methods, including dry media blasting techniques that use wheat starch and plastic media; two hybrid systems, CO<sub>2</sub> pellet blasting and ice blasting; and two wet sys-

tems, the high-pressure or ultra high pressure water technique and slurry blasting, using sodium bicarbonate.

In addition, we have discussed applying thermal energy to coatings through flash lamps—essentially a high-intensity, pulse-light infrared source of energy that has been used commercially on buildings, steel structures, and some aircraft—and lasers that, given a precise control of resonance, time, and temperature, are potentially capable of removing coating.

Our session indicated that there are probably more questions than answers, since many of these technologies are under development or application. We do not have a great deal of information on either cost or removal rates for specific systems, both of which vary from case to case. Although it may be difficult to collect definitive information, these data are needed to make decisions.

Another area is waste management. A spokesman from the Department of Defense talked about efforts to reduce removal wastes by recycling, substituting, or concentrating waste streams. An innovative method uses genetically engineered microbes to biodegrade various plastic media and some paint residue. Another presentation discussed the recovery of methylene chloride vapor with fixed systems and others that are potentially portable.

After reviewing the technology, we decided that the paint removal industry faces the following issues:

- The industry should determine the long-term effects of the various techniques on the substrate. This information is critically important when selecting a viable paint removal process in the aerospace industry since aircraft are made of thin metal skins. It may be difficult to evaluate subtle effects that occur over time; however, this issue has underlined airlines' conservative decisions when picking new paint-removal methods.
- Manufacturers must compile good, objective information on cost, productivity, and how well (given differing techniques) these methods work to remove paint in a given situation. No one paint stripping method is the panacea; therefore, a number of techniques will develop specific market niches.
- Industry should address the increasing use of composites and high technology materials in airplanes and the challenge of

selecting a paint removal method that will be compatible—as well as a method for existing older airplanes for which the composite components have become more porous.

- Manufacturers and consumers should recognize that a synergism may exist between technologies. For example, in one case, paint was chemically softened and then removed by high pressure water blasting. Because there are fundamentally different approaches for removing coating, it may be possible to apply more than one technique sequentially to do the best job.
- The industry's continued use of automated paint removal systems can potentially protect workers, increase productivity, provide consistency that comes from robotics, and lower costs. This is particularly true in the aerospace industry where it may be possible to strip many of the same types of aircraft in one facility. Despite higher capital costs, it might be viable to construct larger facilities that could service many airplanes.
- An exciting prospect is the use of a systems approach designed to rethink the protective coating system on airplanes or other vehicles over the life cycle of the coating system. It may be possible to optimize both the protective features of the coating and the ability to safely, easily, and cost effectively remove it if both coating efficacy and removal are considered as design parameters of a completely new system.

**Comment (Carmine Carbone):** It would be helpful to have capital expense costs and operating costs included in the summary report. Also, I'd like to define the components that make up these costs and scale them to narrow- and wide-bodied aircraft.

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## Household and Commercial Stripping

### ■ Sandra Eberle

As I sit here and listen to my colleagues discuss what went on in their sessions, I hear a lot of similarities. Many of the same challenges are confronting these people. In the consumer and com-

mercial market, the challenges from the furniture refinishers and professional restorers are no greater than stripping wide-bodied airplanes of delicate construction. They include a number of issues that focus on consumer acceptance and both personal and household safety. Examples include refinishers who have their children in playpens in the area where they work and small commercial shops where children work side-by-side with their parents. Participants have environmental concerns about waste and air emissions and also others about material costs in terms of time and labor. Foremost, however, we heard about new products.

We were very fortunate in our panel members. They included professional refinishers and more than a few homeowner users; major chemical companies, who spoke about basic research; and formulators, the people who work on new product ideas. A lot of special needs have to be met for acceptance in this consumer and commercial refinishing market.

I'd like to touch on a couple of themes. First, the barriers to product development that might, in another area, be called research needs. There's a lack of uniform information on product safety—on the toxicity of various ingredients. Each individual formulator seems to be seeking this information from different sources and having different degrees of success. The data may exist but certainly are not readily available.

Safety and toxicity data, if they exist, are open to interpretation. There is no baseline of uniformly agreed-upon standards on what is hazardous or safe—not even for flammability.

The other barrier to product development is the inconsistency in testing information. Products were tested on a variety of substrates; however, removal codings were not uniform. The age of the coating is important, as is the arrangement of the layers and the nature of different coatings.

Although certain inconsistencies exist in the basic types of strippers, formulations are not uniform. Manufacturers use different activators as well as varied amounts of chemicals in the formulations, which makes it difficult to compare a company's work on a methylene chloride-based formulation versus one containing dibasic esters or *N*-methyl pyrrolidone. Everyone is testing them, but they are all testing different formulations so conclusions are inconsistent. A lot of work has gone into optimizing certain formulations, and those products' effectiveness is close to if not the same as that of methylene chloride-based formulations. Again, that conclusion is complicated by the lack of testing uniformity.

Mark Greenfield said that we are all environmentalists, and certainly that came through from each panelist and presenter. There is a concern about the environment but no uniform level of knowledge, understanding, and acceptance.

The history of the development of paint-stripping formulations goes back well before benzene strippers. Manufacturers have made a consistent effort to refine formulations and meet safety and health needs. The more durable coatings being used on furniture require new innovations in stripping formulations. An emerging new issue is the danger to humans from lead-based paint in housing. There will be a greater need to strip architectural elements such as window frames, panel doors, and even walls in dwellings.

All these new products must be accepted by consumers and professionals, who share a unique problem: often the nature of the substrate is unknown. Delicate veneers, exotic woods, or ivory inlay may lie beneath those layers of coatings. The furniture restorer and successful consumer-user do not want to damage that substrate, so they have to be sure the paint stripper will not harm the wood itself or the glues. The consumer has different preferences and experiences other problems than the professional. If professionals can identify the coatings, they may be able to use specific strippers. Even if consumers can identify varnish, they may not be able to pick a specific varnish stripper. So while specialized products may be appropriate for the commercial professional, the consumer probably needs a product with a fairly broad spectrum.

Consumers really hate stripping; it's messy, smells bad, and taking these multiple layers of coatings off is unpleasant. In that context, stripping is just one part of the process but not an end in itself. The consumer refinisher faces multiple issues: whether to darken or stain the wood, problems with bleed through, and the stripper's impact on any new finish. All of this should be taken into consideration when manufacturers develop new products.

Working time, especially for the professional, is important in terms of acceptance. New products that require more time than traditional ones have to overcome consumer expectations about stripping speeds. Consumers also expect to see blistering and lifting; many new products just soften paint. Lastly, if the consumer cannot use traditional tools, that's another detriment to the new product.

In the commercial market, traditional equipment includes pumps and vats. Changes that would vastly reduce exposure and costs while

providing more worker and environmental safety would be necessary for new products.

In terms of safety, the professional faces issues of equipment, changes in process, engineering controls, worker protection, and the adequacy of information about protection. Other issues include

- Respirators—are they effective when working with traditional methylene chloride paint strippers?
- Flammability;
- Lead paint abatement;
- Worker safety;
- Child safety (basic contact with the product or fumes);
- Toxicity, both acute and chronic;
- Use of products indoors or in an enclosed space;
- Labelling. CPSC is surveying to find out if consumers read and heed labeling on methylene chloride-based paint strippers. To what extent are labels effective in changing consumer behavior?
- Eye and skin irritation. The basic issue of exposure is that, all other things being equal, the user will have a greater risk from the more volatile substance than from the one that is less volatile even if toxicity is the same.
- The consumer's ability to follow directions. Can consumers use caustics and acids safely? A certain amount of market history says they will; however, a certain amount says there's a possibility of very serious injuries.
- Environmental concerns, an area where there is the most need for follow-up information.
- Waste, be it waste into sludge streams and landfills or emissions into the air. Very little cognizance is being taken of concern about emissions into the air and recovery of solvents. Materials often require testing to determine whether they are a hazardous waste and then need specialized treatment;
- Communication between formulators and users, both small shop or commercial refinishers and householders. What is

expected of them if they're going to be good environmental citizens?

- Vapor recovery, the whole issue of volatile organic compounds.
- Costs: the cost of the materials versus the amount of the material used; costs of labor, of application time and waiting time; costs in terms of profit margin in the distribution chain; and cost of waste disposal and emission control. Certain new product applications include being able to estimate, consistently, costs for labor, disposal, and material.
- New products. Everybody, unfortunately, is testing something different on something different. Major types of new products include the dibasic esters, *N*-methyl pyrrolidone, traditional

flammable paint stripping products, caustics, and DCM products. Among the new methylene chloride products are various vapor-retardant systems, barriers, glycerins, waxes, additives, gel resins, and innovations that would lessen exposure from the use of DCM products.

- Lastly, new problems. Manufacturers are developing new coatings that are difficult to remove, such as polyester, some of the acid-catalyzed coatings, and certain epoxies.

I would echo the other chairman in saying that we had a great group of people. They were a resource not only when they were speaking but also as an audience. It is clear that many issues need further research and that solutions have been only partially achieved.

# The Next Steps: Planning for the Future

## Katy Wolf

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### ■ Mary Ellen Weber

Dr. Katy Wolf is the director of the Institute for Research and Technical Assistance, a nonprofit organization that provides technical information and helps demonstrate new technologies. Her focus is on industries that use chlorinated solvents and other ozone-depleting chemicals. For the last three years, Katy has been looking at over 14 industries and analyzing reduction of chlorinated solvents.

Before that, Katy Wolf was a researcher at the Rand Corporation, where she worked on use, release, and control measures for ozone-depleting substances in chlorinated solvents. Katy has her B.S. in chemistry, her M.S. in physical chemistry, and a Ph.D. in chemical physics; in addition, she teaches at U.C.L.A. I would like to present Katy Wolf.

### ■ Katy Wolf

I'm glad to be able to speak to you. As you heard from the short biography, halogenated hydrocarbons are my life; I have worked on chlorinated solvents and other ozone-depleting substances for much of my career. They're very interesting. I'm excited about working in all of the industries where these substances are used.

Before I begin, I'd like all of us to thank the EPA for putting on this excellent conference. It has been extremely useful for sharing information about paint stripping. I want to urge EPA to put on conferences focusing on other end-use areas for chlorinated chemicals.

Many people have asked me throughout the conference if anyone had data on using methylene chloride. Production of methylene chloride domestically in 1988 amounted to about 229,000 metric

tons. Demand—which is equal to production minus exports plus imports—amounted to somewhat less, 207,000 metric tons. That figure will vary on yearly, depending on whether exports exceed imports.

Methylene chloride has various end-use applications, the largest being paint stripping. It is important to note here, too, that methylene chloride is a ubiquitous solvent; it's used widely in a whole range of different applications. The category called "other" is very, very large and composed of a number of different applications.

Of the 50,000 metric tons of methylene chloride used for paint stripping, 10,000 metric tons are consumed in original equipment manufacture; 20,000 metric tons in military (the majority), commercial, and other applications; and 20,000 metric tons by consumers. Paint stripping by householders accounts for about two-thirds of total consumer use, with contract stripping by outside furniture refinishers accounting for the remaining third.

Methylene chloride blended with other compounds makes an excellent paint stripper. It penetrates the cured film paint matrix readily, bubbling up the material; with the addition of other chemicals, it can remove all kinds of coatings very quickly, even epoxy-based primers and polyurethane topcoats on military vehicles.

Methylene chloride provides two environmental benefits. Since it does not have a flash point, it's not flammable. Virtually all of the alternatives have flash points, either in the flammable or combustible range. Also, methylene chloride does not contribute to photochemical smog, so under section 111 of the Clean Air Act, it is an exempt material and is usually exempted by local air districts. So firms, to avoid using photochemically

reactive substances, have turned to methylene chloride.

There has been some discussion over the last few days about the regulatory regime that surrounds methylene chloride. I will briefly summarize the information.

- Although the results remain extremely controversial, methylene chloride has tested positively in carcinogenicity trials with certain animal species. Whether or not those data are translatable to human beings remains controversial.
- The Occupational Safety and Health Administration will promulgate a proposed rule to lower the workplace exposure level significantly, from the current level of 500 parts per million to 25 parts per million.
- The Consumer Products' Safety Commission required labeling in the past but has made it voluntary. Household products that contain methylene chloride should be labeled.
- Under the Clean Air Act Amendments, methylene chloride has been designated a toxic air contaminant. It's not clear yet what that will mean, except that, over the next seven years, regulations will be promulgated for paint stripping and other sectors that use methylene chloride. It's likely that certain control technologies will be required, depending upon the industry where the substance is used.
- EPA may also require industries using the substance to adopt maximum available control technology (MACT).
- The California Air Resources Board has also designated methylene chloride a toxic air contaminant. Over the next few years, they, too, will be requiring use of control technology in various end-use sectors. In California, methylene chloride is also named under Proposition 65, which lists chemicals known to cause cancer and birth defects.
- Finally, in California, the Southcoast Air Quality Management District is passing a new rule that will affect methylene chloride users, particularly in the paint stripping category. Users calculate whether or not they exceed the allowable risk level— $10^{-6}$  at this stage. If they do (and it's very likely that paint stripping operations will), then they are required to put in what's called "T-BACT," toxic best available control technology. However, the district has not defined what T-BACT is for any industry, which must be done before the rule becomes effective. Users that exceed the risk will spend money on a control technology that might be denied a permit. The district has already started levying a fee of 19 cents a pound on methylene chloride users, which is significant because the bulk price of methylene chloride is 29 to 30 cents per pound.

Some of the trends in the paint stripping industry that have occurred and some that can be predicted for the near future include:

- Movement away from use of methylene chloride by many auto production firms because of pressure from unions and workers. They still use methylene chloride in various applications where alternatives are hard to find.
- The new OSHA permissible exposure level will move firms away in all sectors because 25 parts per million is an extremely low exposure level. Ventilation levels in the workplace will have to be raised to meet those standards. It's not clear yet whether OSHA will promulgate a proposed rule that will allow use of personal protective equipment for a few years and then require controls.
- The OSHA regulation and the Clean Air Act Amendments and state and local regulations requiring control technology of various kinds will be extremely significant. The interaction between the new OSHA permissible exposure level and control technology is also important. The higher the air flow in the workplace, the larger the air stream that must be treated for a control technology, making it extremely expensive. Furniture refinishers can certainly increase the airflow in the workplace, but they may not be able to afford the control technology required under the Clean Air Act Amendments or local regulation.

In the original equipment manufacturing sector, there are four basic end uses for methylene chloride:

- The first is booth stripping, which is done in many auto assembly facilities and other plants with assembly lines. Parts move

through a paint booth on racks and hangers, and a worker sprays them with a paint gun. The paint that is oversprayed onto the sides of the booth is removed periodically—that's booth stripping.

- When workers change the type or color of the paint, they have to clean the guns and lines—another end use of methylene chloride.
- Paint that is dropped on the floor must also be cleaned up periodically.
- Finally, methylene chloride is used in immersion stripping for racks, hangers, and hooks that are caked with paint and rejected parts that need to be worked.

Firms can use many alternatives to methylene chloride when booth stripping because the paint is usually not cured; therefore, just about any solvent will remove it. In addition, a whole range of other processes are available. Alternatives include 1,1,1-trichloroethane, which will be banned for its contribution to ozone depletion in a few years; high pressure water; sodium bicarbonate; strippable or peelable coatings, which are best used in operations that don't have a huge paint buildup; and various physical methods, such as chiseling the paint off. Some firms recover methylene chloride in paint booths; however, it is an expensive process that usually results in a contaminated product.

Gun and line cleaning can be performed with other chemical strippers or firms can use a gun-cleaning station, which is a 55-gallon drum with a fitting on top for the gun. Instead of spraying the solvent into the atmosphere, you put the gun into the fitting, shoot it, and collect the solvent for reuse.

For immersion stripping, emissions can be better contained by using a water blanket and by covering the vat when it's not in use. Alternatively, firms can use on-site distillation or send the material to be cleaned off-site. Other processes include alkaline acid strippers, a cryogenic technique, and blasting with wheat starch are also options. Firms can also avoid painting altogether; however, it may be more economical to paint and strip in one place, and customers may prefer the painted merchandise.

By the year 2000, use of methylene chloride by original equipment manufacturers will have been reduced to nearly one-eighth of today's level.

In the maintenance stripping sector, there are many alternatives to using methylene chloride.

- Dry abrasives include plastic media and wheat starch; wet abrasives use sodium bicarbonate, high pressure water, and various fracture technologies;
- A whole range of techniques work on spectroscopy: laser, flash lamp, and infrared;
- A biodegradation technique uses microorganisms and takes approximately four or five weeks;
- American Airlines has chosen not to paint aircraft—they put on decals and keep their aircraft polished; and
- Finally, there are evaporation retardants, which, when added to methylene chloride-based strippers, lower both the amount of stripper used for the job and emissions.

In the year 2000, methylene chloride will be used in maintenance stripping only about one-fourth as much as it is currently. In the consumer sector, two-thirds of the methylene chloride sold is used in household stripping and one-third in professional refinishing, primarily for wood-based products although metal and plastic items are also stripped. A variety of alternative chemicals are available, some with flash points in the flammable range, others in the combustible range. Vapor recovery for contract stripping and evaporation retardants may be viable for this market. The combination of the OSHA PEL (permissible exposure level) and control technology that may be required will be difficult for many businesses to meet and may discourage future use of methylene chloride.

Flammable alternatives are low molecular weight hydrocarbons with flash points in the flammable range and include things like acetone and mineral spirits. Most of these substances do not strip cured paint well by themselves, and all of them pose a workplace danger because they are flammable. Also, they are photochemically reactive and generally heavily regulated by EPA in the local air districts. Many have unscrutinized chronic health effects; mineral spirits, for instance, have never been tested for chronic toxicity.

There are a whole range of hydrocarbon solvents with flash points in the combustible range. These are simply higher molecular weight materials made of carbon, hydrogen, nitrogen, and oxygen. We've heard a lot about dibasic esters, *N*-methyl pyrrolidone, and alkyl acetates. These materials are not nearly as volatile as either the

flammable or chlorinated solvents and don't evaporate readily. They remain on the surface much longer and therefore require a longer stripping time.

Hydrocarbon solvents are not exempt from either Clean Air Act or local air district regulations, so they are, by definition, VOCs. They contribute to photochemical smog, even though the evaporation rate is lower than for methylene chloride. Many have unscrutinized chronic health effects. Data on these solvents should be collected and evaluated by the proper government agencies in the next few years.

Some thoughts on the other processes:

- Plastic media blasting is widely used in the maintenance sector. Substrate damage may occur with this particular technology, and many commercial airlines have been reluctant to adopt it. In addition, use of plastic media produces a large volume of waste that, if it contains chromium, is considered hazardous. When using plastic media in a hangar, firms must prevent worker exposure to the dust generated in the stripping process. Since dust control can be expensive, media blasting can require an extremely high capital investment.
- Sodium bicarbonate is a wet, abrasive technique that's very effective. Since corrosion might occur if it is used to strip whole air frames, firms generally are using this technique on panels, which are then neutralized with an acid rinse. This method generates a liquid waste stream that must be put through a wastewater treatment plant.
- With carbon dioxide blasting, carbon dioxide can add to the global warming problem. However, there is no net addition of carbon dioxide from this paint stripping method because the carbon dioxide was taken from other processes that would have emitted it. Nevertheless, California's Southcoast Air Quality Management District always regulates sources in its jurisdiction, so there may be future rulings on the carbon dioxide technique.
- Laser, flash lamp, and infrared technology may result in decomposition products from the paint that are dangerous. These methods can make chrome airborne and

convert polyurethanes into cyanides, for instance.

I'd like to talk briefly about how the regulatory process has worked over the last 15 years. A chemical is used for a number of years, then evidence starts emerging that it might pose health and environmental effects of various kinds, so it is designated an evil chemical. Sometimes limited action is taken, and later stronger action, either a ban or environmental controls that are designed to reduce or eliminate the use of the chemical.

Now, what's wrong with this process? One problem is that government offices, even within the same agency and certainly among different governmental agencies, have different agendas; nobody is taking an integrated look at the problem. For example, the global change office at EPA will be banning depleting substances over the next decade. However, EPA is practically marketing photochemically reactive substances; they're encouraging people to move out of the ozone-depleters into the smog-producing chemicals.

On the other hand, the Southcoast Air Quality Management District has put such stringent regulations on smog-producing chemicals that, in effect, they've moved everybody into the ozone depleters. So we have this tension between different government agencies. Also, nobody wants chemicals to go in the air, neither the Southcoast Air Management District nor the ozone depletion people, so they encourage cleaning solutions that will shove the whole problem into the sewer. A different office, the Office of Water at EPA, would be concerned about these releases. Nobody seems to have overall responsibility. Rarely are government people familiar with the actual processes. They will discourage the use of particular chemicals but not be aware of what processes people are adopting and what chemicals they're using instead.

I would like to commend the Office of Toxic Substances at EPA for holding this conference because it is useful to have a dialogue back and forth between the Agency and industry. The Office of Toxic Substances is positioned perfectly in EPA. It doesn't have responsibility for any particular medium nor does it ban any particular set of substances that contribute to a particular problem. So it is most likely to take this integrated approach.

These various offices at EPA or other governmental agencies pick out a chemical that they dislike and ban it. Unfortunately, they don't know about the alternatives, which are not adequately scrutinized by the time they are marketed.

Many of the paint stripping alternatives being proposed have not been adequately scrutinized for their health and environmental effects. There simply is no systems approach to regulation, and this encourages the use of dangerous processes and alternatives.

So what does this mean for paint stripping, in particular? Because the regulations on methylene chloride are extremely severe, many users will simply stop using it. We hear a lot about how nothing else can perform as well. It doesn't matter. Once something goes on these lists and the regulations become stronger, people won't continue to use it. It simply is not cost effective to do so, no matter how technically desirable the substance. Users will adopt alternatives, and at the moment, these substances are more or less unrestricted.

What can we do about this? We have to get back in gear and agree that our aim is not to ban

ozone-depleting substances or get rid of one chemical but to better protect human health and the environment overall. The regulators should ask themselves if the current regime in place and pending on methylene chloride is what they want. And, at that time, they should be aware that methylene chloride use will decrease significantly over the next several years and use of many alternatives will increase. If this is not the desired path, then rethink the regulations and make them less stringent because almost certainly what's in place will move people toward the alternatives.

If it is the desired path, we need to look at all the alternatives, to scrutinize their health and environmental effects as rapidly as possible. If we identify severe problems, we have to restrict the alternatives as we have methylene chloride and prevent their use in the marketplace.

# Closing Summary

## Mary Ellen Weber

*Office of Toxic Substances  
U.S. Environmental Protection Agency  
Washington, D.C.*

**B**efore I summarize, I would like to publicly recognize people from the Office of Toxic Substances who have worked long and hard on this conference. It is the first conference that we at EPA have ever put on, and I would like to acknowledge Libby Parker, Dan Axelrad, Susan Krueger, and Bob Lee. I'm also grateful to our contractors, JT&A, inc., and Abt Associates.

The Office of Toxic Substances is anxious to start EPA's next 20 years in a new vein. We are painfully aware that there has been a separation of activities between the various offices at EPA, and the sort of "it's not in my territory" kind of mentality. That has been a result of the existing statutes under which we operate and not because people fail to recognize the implications of what they do.

TSCA is uniquely positioned, however, to deal in a multi-media fashion to try to help EPA's other offices coordinate their activities. We already have a number of interoffice task forces on clusters of chemicals or industries as a whole. That is going to be the way of the future, to try to look at an entire package of problems, a whole industry, and examine it from a multi-media standpoint—air, water, solid waste.

Some of the new code words we're using—like life cycle—may sound like jargon, but they are deeply part of the actions, practices, and philosophies at EPA. We are committed to looking at the product from the point of view of production use and disposition. And our method is not going to be nearly so much focused on traditional command and control regulations, which ultimately in its extreme is the "ban approach" to things, but rather on trying to work on information exchange and technology transfer. We want to be a center that provides new information on technologies and methods that are available or emerging, and perhaps to even force some technology in approaching

risk reduction, hopefully from a more voluntary, cooperative standpoint.

A number of programs are underway that we think are going to make it much more financially attractive for producers and users of chemicals to use and distribute substances in an environmentally responsible way—and to take that stance as a marketing approach. Companies are finding environmentalism sells. Also, companies are discovering that if they capture wastes instead of discarding them, they are recapturing products and saving money.

We recognize that there are some trade-offs in the new paint stripping methods. You put a lid on the vat to stop vaporization, but then you've got to dispose of a lot more of the product. In the past, we've failed to consider the potential dangers of alternatives when we've looked at banning or regulating substances, their use, production, or distribution. Unfortunately, we also have limited resources—and that's where you all come in. We need your help. We need information and test data. We will be happy to give you our data, and we are trying much harder to be sure that when we try to contain a problem here, we don't cause a problem there.

The accomplishments of this conference are numerous. One of our original goals was to foster a spirit of what we're now calling "product stewardship." It means having the producers (particularly) but also the users take responsibility for informing the public about the safe uses of their products.

Another goal of the conference was to increase international understanding. It is clear that there will probably always be certain difficulties because of differences in cultures, philosophies in risk, and scientific disagreements. But we must recognize those differences and make them explicit. I think we have accomplished that, but even more impor-

tantly, we have made it possible for some of our international guests to exchange information with each other and with us on where they're going and where they've been. If we're looking for alternatives and substitutes for chemicals, we need test information, and the United States no longer has the resources or the ability to do all of the testing for everybody everywhere.

Another thing I've heard is that industry has enjoyed the opportunity to talk face-to-face with those of us who are regulators. We are delighted with this opportunity to network, and there have been some surprises. The big surprise for me was discovering that there has been networking not only within government agencies at this conference but also within individual companies that

would not have happened had this conference not taken place.

The conference has made much more explicit the understanding that any time you want to mitigate a risk, you must deal with the trade-offs. We cannot look at solutions to health and environmental problems in isolation because there are ripple effects. We need to look at the safety and efficacy of substitutes when suggesting them as alternatives to our current practices. And we've had a chance to look at a multi-media approach to risk reduction in paint stripping.

We're very grateful to all of you for coming, and I hope that our paths cross again.

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# **APPENDIX A**

## ***Attendees List***

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# INTERNATIONAL CONFERENCE ON REDUCING RISK IN PAINT STRIPPING

*Presented by the  
U.S. Environmental Protection Agency*

*February 12-13, 1991 • Omni Shoreham Hotel • Washington, D.C.*

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# **APPENDIX B**

## ***Supplemental Information***

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# Contents

*This section contains reports not presented at the conference but submitted as additional paint stripping information.*

Turco Environmentally Acceptable Paint Stripper  
*Turco Products, Inc.*

Armex Sodium Bicarbonate Blast Media Integrity on Aluminum Surfaces  
*J.H. Van Scriver Associates*

Environmentally Acceptable Paint Removal Systems  
*Ardrox*

Reducing Hazardous Risks of Chemical Stripping through Effective Waste Treatment  
*W.L. Becktel*

Plastic Media Blasting—The Wise Alternative to Chemical Stripping  
*Richard A. Dotson*

Significant Factors of Media Selection for the Dry Stripping Process  
*Bob Kerr*

Non-methylene Chloride Paint Removers Based on *N*-methyl-2-pyrrolidone (NMP) and Thickened with Ethylhydroxyethylcellulose (EHEC)  
*Harold F. Haag*

Solvent Recovery Using the Brayton Cycle Heat Pump  
*Paul E. Scheihing*

**ATO**  
**ATOCHEM**  

---

*off aquitaine*



**ENVIRONMENTALLY ACCEPTABLE PAINT STRIPPER**

**TURCO PRODUCTS, INC.**  
7300 BOLSA AVENUE  
WESTMINSTER, CALIF. 92684-3600  
TELEPHONE NO. 714/890-3600



**TECHNICAL**

**DATA**

**ATO**  
**ATOCHEM**  
elf aquitaine

**BULLETIN**

**NO.** 957

TURCO PRODUCTS, INC. • 7300 BOLSA AVENUE, WESTMINSTER, CALIFORNIA 92684-3600 • 714/890-3600

**TURCO<sup>®</sup> E. A. STRIPPER**  
**ENVIRONMENTALLY ACCEPTABLE PAINT STRIPPER**

**DESCRIPTION:**

**TURCO<sup>®</sup> E.A. STRIPPER** is a thixotropic, light green liquid remover developed for stripping resistant finishes such as epoxies, epoxy primers, polyurethanes, alkyds and similar catalyzed paints.

**TURCO E.A. STRIPPER** paint remover offers a significant advance in improving work place safety since it does not generate obnoxious fumes or odors and is free from methylene chloride, chlorinated solvents, phenols, chromates, ammonia and amines.

**TURCO E.A. STRIPPER** can be used on aluminum, mild steel, cast iron, and titanium when used as directed. **TURCO E.A. STRIPPER** is not recommended for use on high strength steel and magnesium. **TURCO E.A. STRIPPER** meets the "Effect on Metals" requirements of MIL-R-81903 A (AS).

**FEATURES:**

**TURCO E.A. STRIPPER** offers these features:

1. Flash point over 200°F, Pensky Martens.
2. Used as received. No mixing or dilution required.
3. Clings to vertical and overhead surfaces.
4. Free from obnoxious fumes and odors.
5. Used at ambient temperature, above 60°F.
6. 395 gr/l V.O.C. @ <2 mm Hg V.O.C. Vapor Pressure

**USE INSTRUCTIONS:**

**Application:** Apply a thick, uniform coating to surface being stripped by means of nonatomizing spray or by brushing. Allow sufficient time for stripper to work. Agitation with a stiff bristle brush will aid in removal of the finish.

**Removal:** Rinse with high volume, high pressure water or squeegee off bulk of stripped paint and **TURCO E.A. STRIPPER**, then remove residues with emulsion cleaner and/or wipe solvent. (See TURCO 6709).

**DISPOSAL INFORMATION:**

Dispose of spent remover and paint residue per local, state and regional regulations. Refer to your TURCO MATERIAL SAFETY DATA SHEET for additional disposal information.

**CAUTION!**

**TURCO<sup>®</sup> E.A. STRIPPER** contains formic acid. Avoid contact with eyes, skin and clothing. Do not take internally. Do not spray in confined areas. Avoid prolonged breathing of vapors. Use with adequate (equivalent to outdoor) ventilation.

Protective clothing, such as a chemical face shield or goggles and gloves should be worn and a NIOSH-approved respirator equipped with a mechanical filter should be worn for mist conditions.

Store containers at a temperature between 30°F and 120°F.

Before using this product refer to container label and TURCO MATERIAL SAFETY DATA SHEET for additional precautionary, handling and first aid information.

**NOTICE:**

The above information and recommendations concerning this product are based upon our laboratory tests and field use experience. However, since conditions of actual use are beyond our control, any recommendations or suggestions are made without warranty, express or implied. Manufacturer's and seller's sole obligation shall be to replace that portion of the product shown to be defective. Neither shall be liable for any loss, damage, or injury, direct or consequential, arising out of the use of this product.

**For over 60 years, Turco Products has been a leader in supplying formulated chemical specialty products to industry. Over that time, Turco Products has acquired and enjoyed a reputation as an innovator in the markets it serviced. In the past, much of the research effort expended by Turco Products was concentrated on enhancements of performance, reductions of cost and general improvements in processing technologies. In the more recent past, and especially in the last five to ten years, more and more of that effort has been devoted to reducing or eliminating environmental and health concerns involved with the use of some of these products, such as paint removing compounds. This paper describes briefly one of the fruits of this research, a thickened paint stripper for removing aircraft/aerospace coatings, such as polyurethanes and epoxies. This new product contains no chlorinated solvents, no highly toxic organic solvents, no phenols or cresols, no chrome compounds and no known carcinogens. It is currently undergoing field test and is called Turco EA Stripper.**

**The environmental concerns alluded to above have resulted in increasingly stringent regulations governing the use of chemicals known or expected to cause damage to the environment or ecology. These have taken the form of outright bans on certain chemicals in some locations, restrictions on VOC content, restrictions on vapor pressure, restrictions on the weight of organic solvents that can be emitted to the atmosphere, restrictions on waste disposal, and other similar measures. Responsible companies support these as necessary to protect the one environment in which we all have to live.**

**In addition to environmental concerns, the last ten or fifteen years have seen the focus of much attention on protection of the health of workers and the community at large. This has resulted in a much greater awareness on the part of both affected groups to the chemicals to which they are exposed. The "duty to inform" that has been imposed on chemical companies by OSHA and numerous community Right to Know measures**

has raised the consciousness of these groups, in particular with respect to known or suspected carcinogens. This has naturally led to pressure to remove these where possible. Again, responsible companies support these efforts to insure a safe work-place both for their own workers and for those of the companies using these products.

Many of these concerns with regard to paint strippers have focused on methylene chloride. Probably the most far-reaching of these questions relate to the possible carcinogenicity of methylene chloride and to the disposal problems for waste containing very low levels of methylene chloride.

In 1986, methylene chloride was added to the NTP list of chemicals that may reasonably be expected to cause cancer in humans. This addition to the NTP list was based on evidence that has been the subject of some debate as to its validity and relevance, but the mere fact of its presence on the list made it necessary to show, on material safety data sheets and labels for products containing methylene chloride, warnings that the product contained a suspected carcinogen. This, of course, caused concern on the part of many users of products containing methylene chloride. Many user companies responded by restricting use of these products to designated areas where vapor concentrations could be more readily controlled, providing greater ventilation in those areas where methylene chloride is handled, providing respiratory protective devices to workers, or some combination of these three. Obviously a more suitable answer would be elimination of methylene chloride, and replacement with a less toxic material.

Disposal of waste containing methylene chloride is increasingly difficult and expensive. Very small amounts of methylene chloride may contaminate very large amounts of rinse water to the extent that the water must be treated to remove methylene chloride or it must be disposed of as hazardous waste. These regulations are already expensive to

comply with and they can only be expected to be more stringent and expensive in the future. Here, too, the most suitable answer is to eliminate methylene chloride wherever possible and replace it with a less polluting alternative.

Turco Products has enjoyed a long history of innovative solutions to industry problems in many areas, especially paint stripping. Some of the more noteworthy advances in paint stripper technology introduced by Turco Products were the first use of methylene chloride in paint strippers, development of the first truly effective epoxy and polyurethane strippers, the first effective use of phenol or cresol in paint and carbon removers, the first effective use of evaporation retardants, the first acid-activated epoxy stripper, and the first embrittlement-safe paint strippers, as well as a long and continuing list of new approaches and new solutions to other difficult technical problems.

In other areas, responding to environmental and worker exposure concerns, Turco Products has developed many products eliminating chrome compounds, others eliminating phenols and cresols, still other water-based products for use in replacing solvent degreasers, hot tank strippers eliminating chlorinated solvents, phosphate-free cleaners, and many others. Until, now, however, there has been no satisfactory viscous, spray-on stripper effective on resistant aircraft/aerospace coatings.

Turco EA Stripper is designed to meet that need. It is the first in a series of products under development in a major research project. These will be known as the "EA", or Environmentally Acceptable, products and will feature products that had been traditionally based on chlorinated solvents, or other environmentally unacceptable components. These will include paint strippers, carbon removers, chem-mill maskants, coatings and other products, reformulated to eliminate those unacceptable ingredients.

**Turco EA Stripper is a unique product, quite unlike previously available non-chlorinated paint strippers. It utilizes a novel approach to this problem, and is the subject of pending patent application. It is slightly acid, viscous, pastel green liquid. Although all chemicals, including water, have some degree of toxicity and can be hazardous if used improperly, Turco EA Stripper contains only ingredients that are normally thought of as relatively non-hazardous. It contains no known or suspected carcinogens. Although slightly acid, the acid is present only as a dilute solution of a common organic acid in water. It is not aggressive enough to constitute a corrosive hazard to skin, although, of course, it is good practice, based on common sense, to avoid skin contact. The odor is mild and generally considered not objectionable. The composite vapor pressure, including the contributions of all organic material and water, is low, so vapor concentrations are low. It contains no so-called exempt solvents.**

**Turco EA Stripper strips most of the normally encountered aircraft and aerospace coatings. This includes epoxies, polyurethanes and the most difficult epoxy primers. The appendix to this report shows performance data for Turco EA Stripper on several typical paint schedules. These were run by an independent testing lab. As may be seen from the data, stripping proceeds at an acceptable rate. Under normal conditions, workers may continue to work on the inside of the aircraft while stripping continues on the outside. Depending on local regulations, waste EA Stripper may be disposed of as combustible waste. If the acid is neutralized, none of the components has a RCRA number and none is an EPA regulated waste. Paint is generally stripped in a manner analogous to a methylene chloride based stripper, by blistering the paint and lifting it from the surface in a bond release mechanism. Sometimes the degree of blistering or the extent of swelling is somewhat greater for paints stripped with Turco EA Stripper than for those stripped with conventional methylene chloride based products. Turco EA Stripper will, because of its extremely low vapor pressure, stay wet and active for**

a considerably longer period of time than methylene chloride based strippers. This may be of considerable advantage when the coating is very resistant and stripping times are prolonged. This allows Turco EA Stripper to strip some resistant coatings in a single application, while traditional strippers may require several, due to their tendency to dry on prolonged standing.

Turco EA Stripper has several significant advantages over traditional methylene chloride and methylene chloride/phenol strippers. It is inherently a much safer product for the worker to use. It inherently results in much reduced solvent emission and consequent exposure for the community at large. It is an effective, versatile stripper. It often may strip to bare metal in a single application, while traditional strippers may require several applications and some hand work to achieve the same final degree of stripping. Although it cannot be simply flushed down a drain and discharged to a POTW, it requires much less onerous treatment and will not contaminate large volumes of rinse water that must then be treated before disposal.

With these significant advantages, however, there are some limitations. Turco EA Stripper is somewhat more costly than traditional strippers. This higher material cost, however, is often balanced by lower overall operating costs. These lower overall costs may be expected due to lesser material consumption, lower treatment and disposal costs, and the ability to carry on other maintenance or overhaul operations while stripping is in process. Stripping times are also often somewhat longer, as might be expected. This is undoubtedly due to the slower penetration time of alternate solvents compared to methylene chloride, and is probably related to the greater molecular size of alternate solvents. This extra time requirement is most often in the neighborhood of 30 minutes to 90 minutes, however, and may be of no real significance in the overall strip and repaint schedule. At lower temperatures, however, this need for more time becomes

greater and begins to be of much greater significance at temperatures less than about 60-65°F. At higher temperatures, however, the reverse is true and stripping becomes feasible when traditional strippers become impractical due to excessive evaporation. This becomes important at temperatures of 90°F and above. Finally, as with all acid products, including aluminum brighteners, deoxidizers and conversion coatings, Turco EA Stripper is corrosive to magnesium and will cause hydrogen embrittlement of high strength steels. Assemblies containing these alloys will have to be masked off prior to stripping operations.

Other alternatives to methylene chloride based strippers are currently under evaluation in industry. These generally involve various forms of blasting. The means generating the most current interest are those using plastic media, carbon dioxide pellets, and high pressure water blasting. These generally suffer from the same deficiencies. They tend to be slow and labor intensive. They may result in worker exposure to dust, both from the blast media and the paint being removed. Dust from strontium chromate or zinc chromate primers would be of particular concern, since both are recognized human carcinogens. Dust would also be of serious concern if it enters wing fuels tanks, fuel lines, hydraulic lines, etc. Finally, damage to the substrate is a very real concern and requires substantial engineering controls and quality assurance monitoring to avoid this possibility.

With all of these concerns, however, some feel that this is a viable approach. As an aid to mechanical removal, especially with high pressure water blasting, Turco Products offers a product similar to Turco EA Stripper that may be used to soften paint and thus facilitate removal. This is a neutral product, safe on magnesium and high strength steel, and is called Turco Paint Softener. This method, softening the paint and stripping with high pressure water, is the subject of considerable interest in Europe.

**With the introduction of Turco EA Stripper, Turco Products continues its tradition of offering innovative, cost-effective solutions to industry problems. Over the next several years, Turco Products expects to expand and fill out its line of EA products and fulfill its commitment to help provide a safe work place and a healthy environment for all to enjoy.**

**APPENDIX**

TURCO EA STRIPPER

- |    |   |          |
|----|---|----------|
| 1. | Primer: BMS 10-72 Ty VI<br>Topcoat: BMS 10-72 Ty VI | ½ hour   |
| 2. | Primer: BMS 10-72 Ty VI<br>Topcoat: BMS 10-60 Ty II | 1 hour   |
| 3. | Primer: IS-F3-100<br>Topcoat: BMS 10-72 Ty VI       | 1½ hours |
| 4. | Primer: Mil-P-23377<br>Topcoat: Mil-C-83286         | 1 hour   |
| 5. | Primer: BMS 10-11 Ty I                              | 1½ hours |
| 6. | Primer: BMS 10-20 Ty II<br>Topcoat: BMS 10-11 Ty II | ½ hour   |
| 7. | Primer: Mil-P-26915                                 | 1½ hours |
| 8. | Primer: BMS 10-72 Ty VI<br>Topcoat: BMS 10-72 Ty VI | 1 hour   |
| 9. | Primer: BMS 10-11 Ty I Class B                      | 1 hour   |

NAS:cp

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April 19, 1990  
SMI/REF: 900361  
Page 3

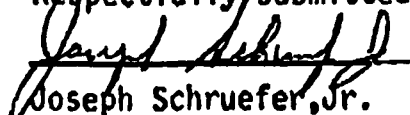
Report of Test

TURCO EA STRIPPER

Requested: Test for conformance to Mil-R-81903A (AS) Special Test.

Result of Test

- 3.6 The panel after the rinse test requires wiping with a solvent before Koropon system is applied.
- 3.7 Test panels of aluminum QQ-A-250/5 painted to the requirements of Table II using Desoto Super Koropon Grey did strip within 80 to 90 minutes. The control stripper did strip within 26 minutes.
- 3.8 The residue is partially removed with water. The panel requires cleaning or wiping with solvent before refinishing.

Respectfully submitted,  
  
Joseph Schrufer, Jr.

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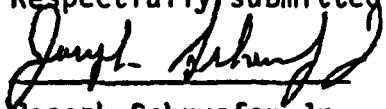
Turco Products, Inc.  
7300 Bolsa Avenue  
Westminster, California 92684-3600

April 25, 1990  
SMI/REF: 900361

## TURCO EA STRIPPER

	approximate stripping time
Mil-R-25134B Lacquer Panel A	30 min.
Mil-R-25134B Lacquer Panel B	30 min.
Mil-R-25134B Enamel Panel C	35 min.
Mil-R-81294C Epoxypolamide	55 min.
Mil-R-81294C Polyurethane	65 min.

Tests are spot tests using the procedure stated in Mil-R-81903A, paragraph 4.5.5. Times are approximate on uncertified panels.

Respectfully submitted,  
  
Joseph Schrufer, Jr.



Materials and  
Corrosion  
Engineering

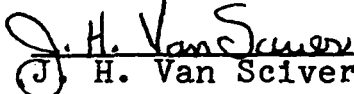
**ARMEX SODIUM BICARBONATE BLAST MEDIA  
INTEGRITY ON ALUMINUM SURFACES**

PREPARED FOR:

Church & Dwight Company, Inc.  
Princeton, N. J.

PREPARED BY:

J. H. Van Sciver Associates

  
\_\_\_\_\_  
J. H. Van Sciver, P.E.  
President

DATE: April 30, 1990

## ARMEX SODIUM BICARBONATE BLAST MEDIA INTEGRITY ON ALUMINUM SURFACES

### INTRODUCTION

In early 1989, test data on the integrity of aluminum surfaces in sodium bicarbonate solutions was developed. This work was presented at the DOD Advanced Coating Removal Conference in April 1989. Three types of testing were utilized: electrochemical corrosion testing, immersion testing as per ASTM F-483 and sandwich testing as per SAE Aerospace Recommended Practice 1512A.

Results of this testing showed sodium bicarbonate to have a low corrosion rate of 0.5 mpy (mils per year) at 120°F. Good correlation was obtained between the three test methods. For comparison, phosphoric acid, sodium carbonate, acetic acid and sodium chloride solutions were immersion tested. All had higher rates than sodium bicarbonate. The buffering capacity of sodium bicarbonate was shown to be large. Although sodium bicarbonate will decompose a few percent with time and temperature, sodium sesquicarbonate is formed which has great pH buffering capacity. Even a 50% sodium bicarbonate/sodium carbonate mixture had a low rate of 3 mpy. Corrosion rates by polarization resistance are attached.

### EXPERIMENTAL PROCEDURE AND RESULTS

Some users of Armex sodium bicarbonate blast media have observed a staining effect on test panels which is cosmetically undesirable. Recent work has been completed to identify an appropriate inhibitor to eliminate this discoloration, lower corrosion, and at the same time greatly reduce the corrosion in other solutions including sodium carbonate. This inhibitor system has been identified.

Six candidate inhibitor systems were investigated. Various combinations of silicates, borates, nitrites and organic inhibitors known to inhibit aluminum were tested at 120°F. All six inhibitors lowered the corrosion rate of 1% and 10% Armex with Inhibitor G having the largest rate reduction (94%).

Solid sodium bicarbonate at high temperatures will decompose into sodium carbonate and carbon dioxide. The six candidate inhibitor systems were tested in 1% and 10% sodium carbonate. Again Inhibitor G exhibited an effective large rate reduction (99%).

Immersion and sandwich testing was conducted on inhibited (Inhibitor G) sodium bicarbonate, inhibited sodium carbonate and comparative solutions. Immersion testing as per ASTM F-483 at 160°F showed the two inhibited solutions to have the lowest rates of all solutions tested; including tap water and distilled water. Phosphoric acid, Mil-R-81903 acid stripper and sodium chloride samples pitted severely.

Sandwich testing conducted as per ARP 1512 revealed no corrosion or staining of the aluminum with inhibited sodium bicarbonate or sodium carbonate.

Samples of aluminum 7075, 2024 and 7075 ALC were immersion tested for one year at 120°F in 1% and 10% Armex. Corrosion rates were not measurable after this exposure.

### SUMMARY

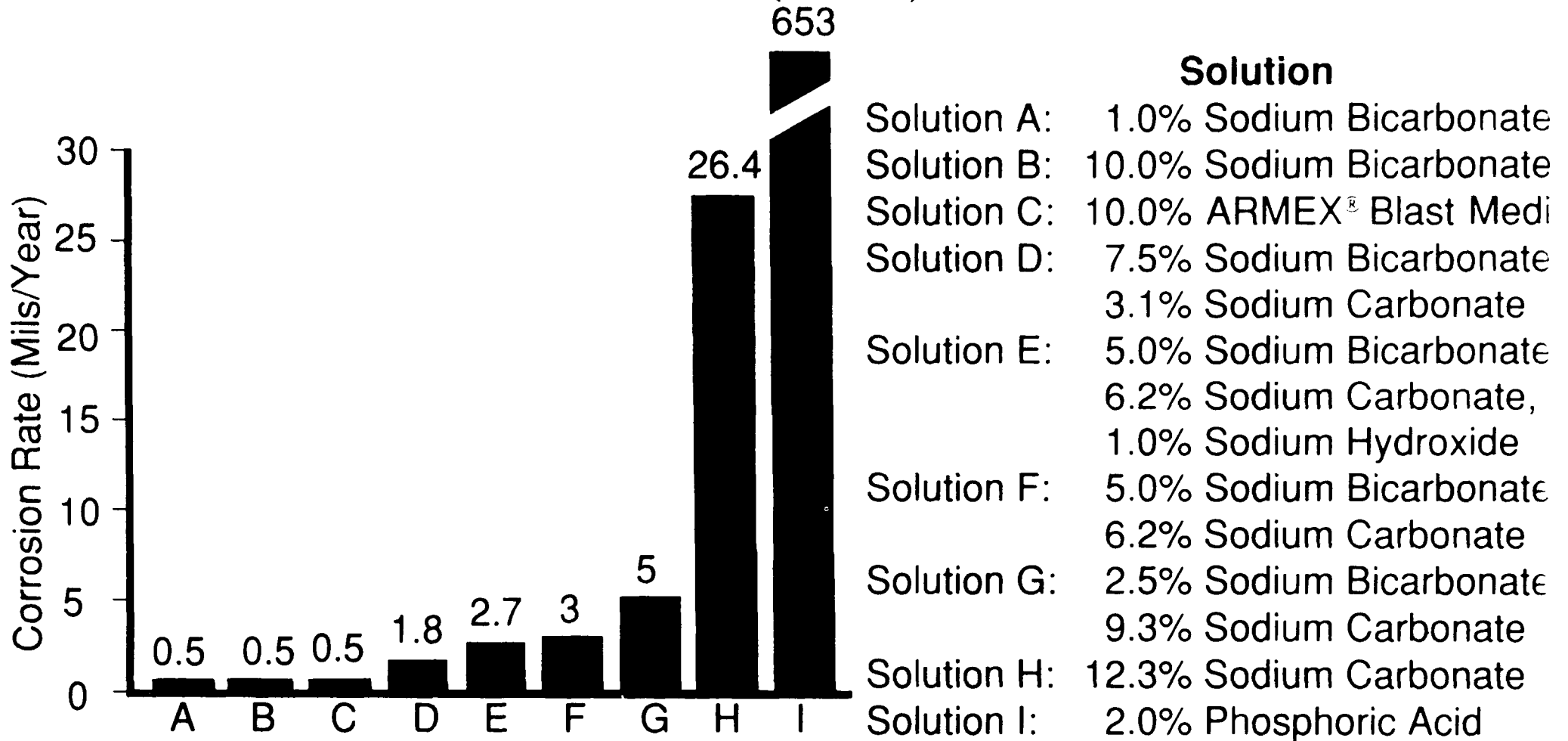
This work has shown that an effective inhibitor system has been identified for Armex blast media. Electrochemical, immersion and sandwich testing in inhibited solutions has shown a 94% reduction of corrosion rates at 160°F and no staining of aluminum 7075, 2024 and 7075 ALC.

Sodium carbonate is also effectively inhibited with a rate reduction of 99% and no staining of aluminum 7075, 2024 and 7075 ALC.

One year immersion samples at 120°F in Armex solutions had negligible corrosion.

# Corrosion Rates by Polarization Resistance

Mils per Year  
Aluminum 7075 - T6  
49°C(120°F)

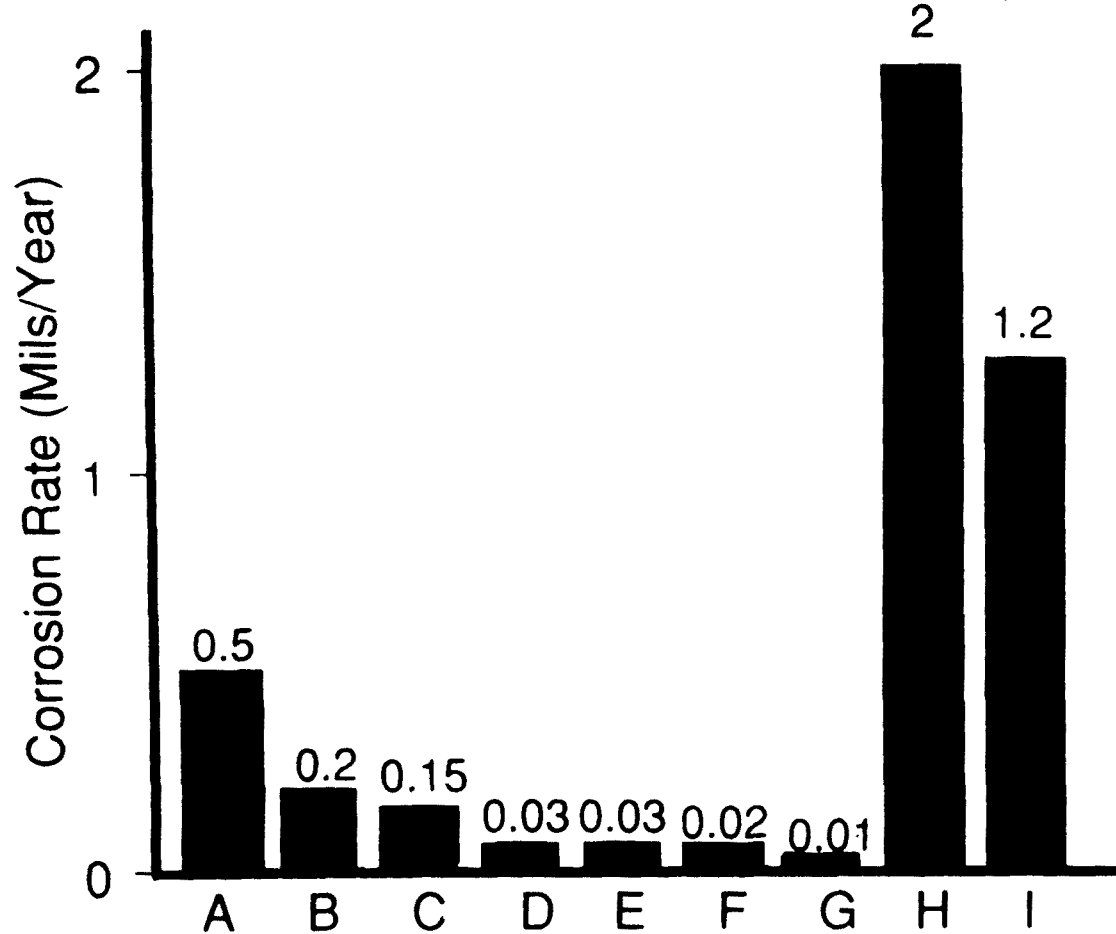


# Corrosion Inhibition 1% ARMEX<sup>®</sup> Blast Media

Aluminum 7075 - T6  
49°C (120°F)

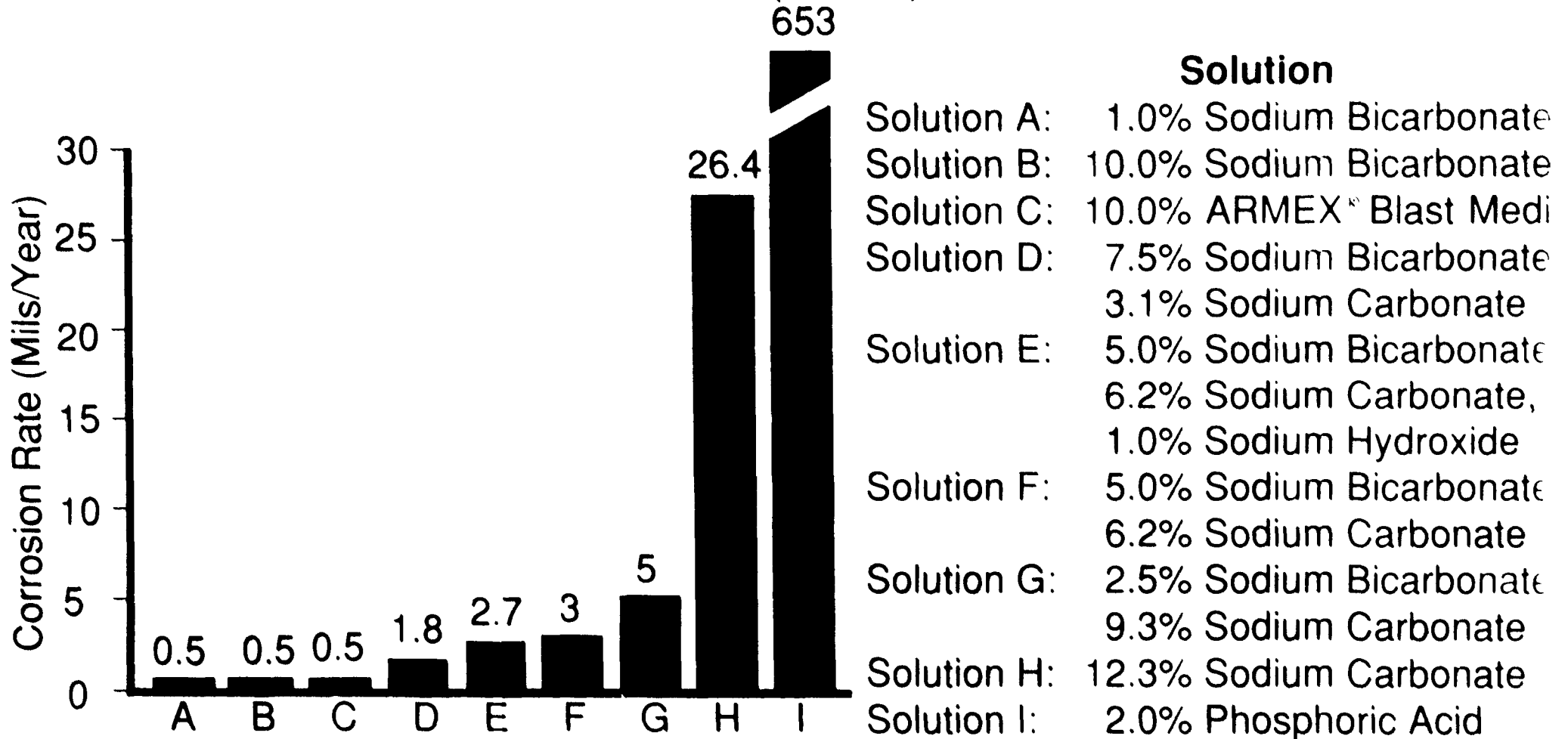
## Solution

- Solution A: 1% ARMEX<sup>®</sup>
- Solution B: 1% ARMEX<sup>®</sup> + Inhibitor A
- Solution C: 1% ARMEX<sup>®</sup> + Inhibitor E
- Solution D: 1% ARMEX<sup>®</sup> + Inhibitor C
- Solution E: 1% ARMEX<sup>®</sup> + Inhibitor E
- Solution F: 1% ARMEX<sup>®</sup> + Inhibitor F
- Solution G: 1% ARMEX<sup>®</sup> + Inhibitor C
- Solution H: Synthetic Tap Water -  
ASTM D1193
- Solution I: Distilled Water



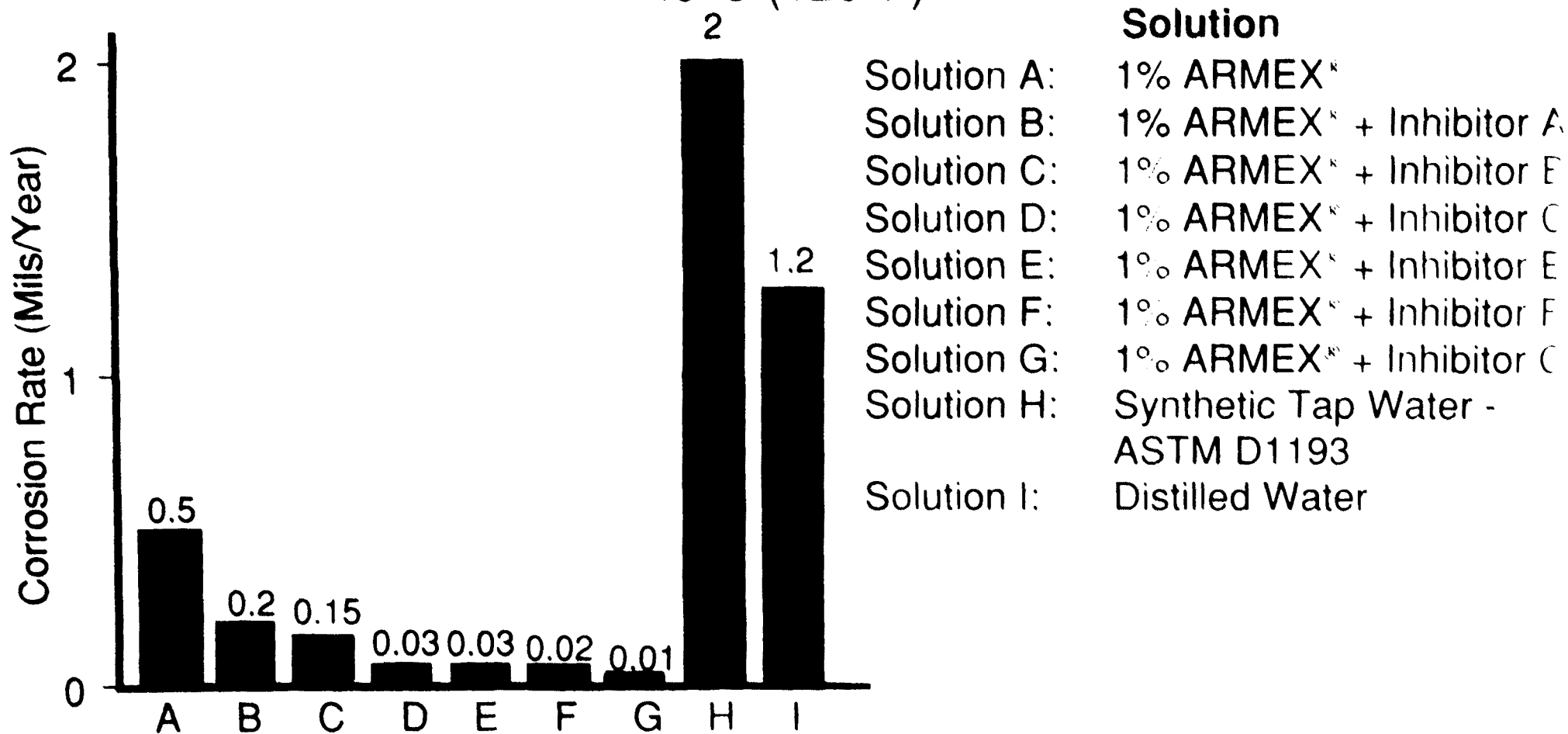
# Corrosion Rates by Polarization Resistance

Mils per Year  
Aluminum 7075 - T6  
49°C(120°F)



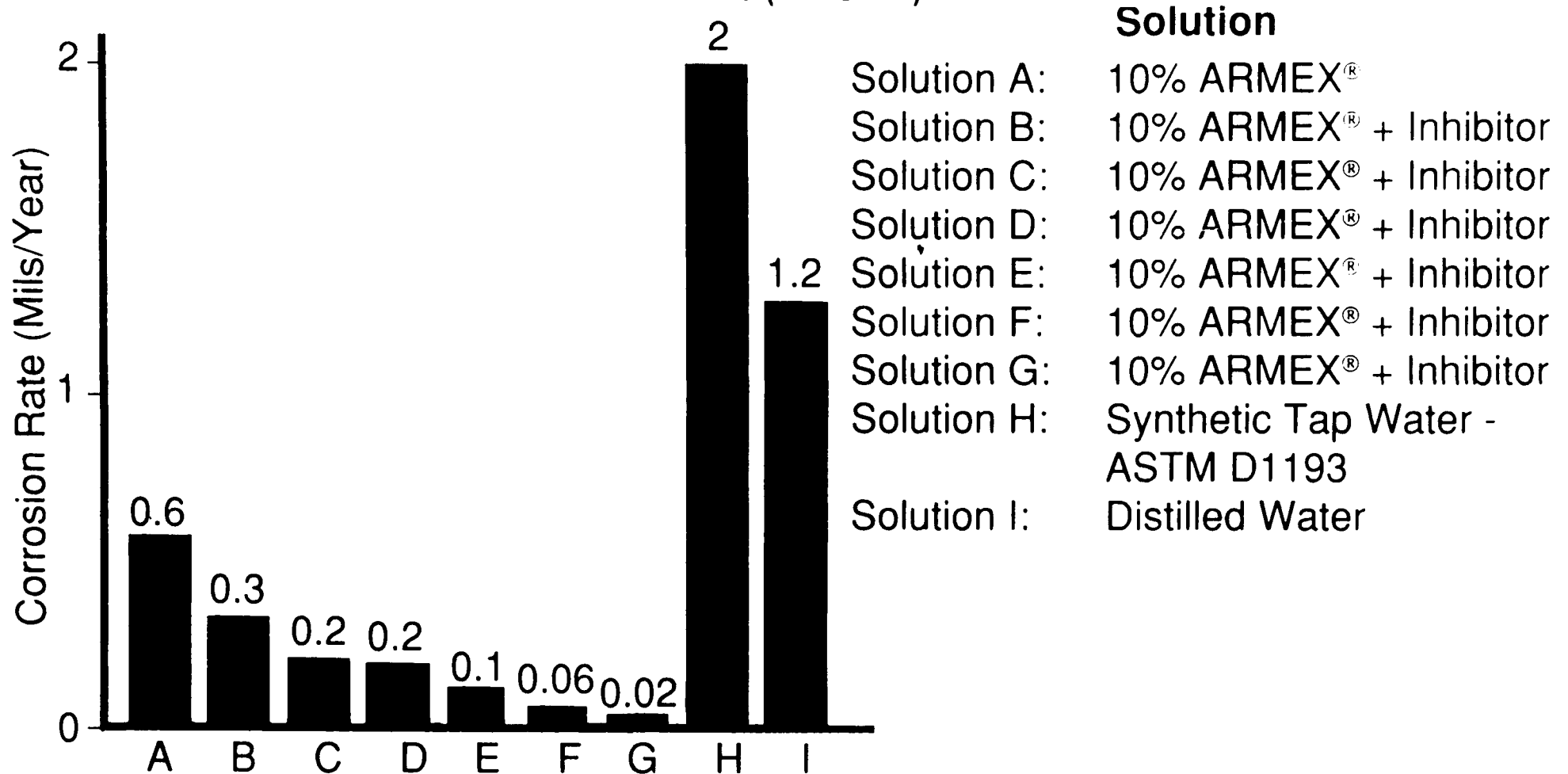
# Corrosion Inhibition 1% ARMEX® Blast Media

Aluminum 7075 - T6  
49°C (120°F)



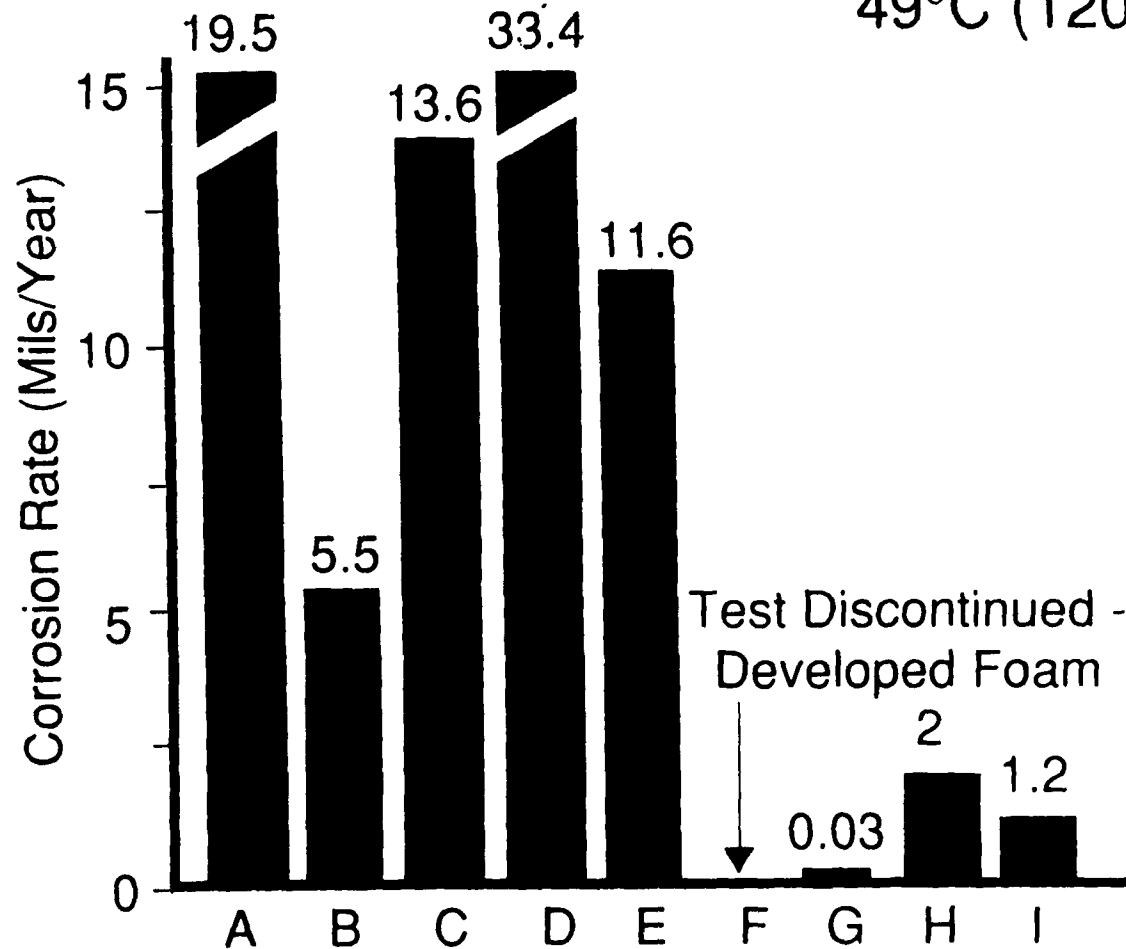
# Corrosion Inhibition 10% ARMEX<sup>®</sup> Blast Media

Aluminum 7075 - T6  
49°C (120°F)



# Corrosion Inhibition 1% Na<sub>2</sub>CO<sub>3</sub> (Sodium Carbonate)

Aluminum 7075 - T6  
49°C (120°F)



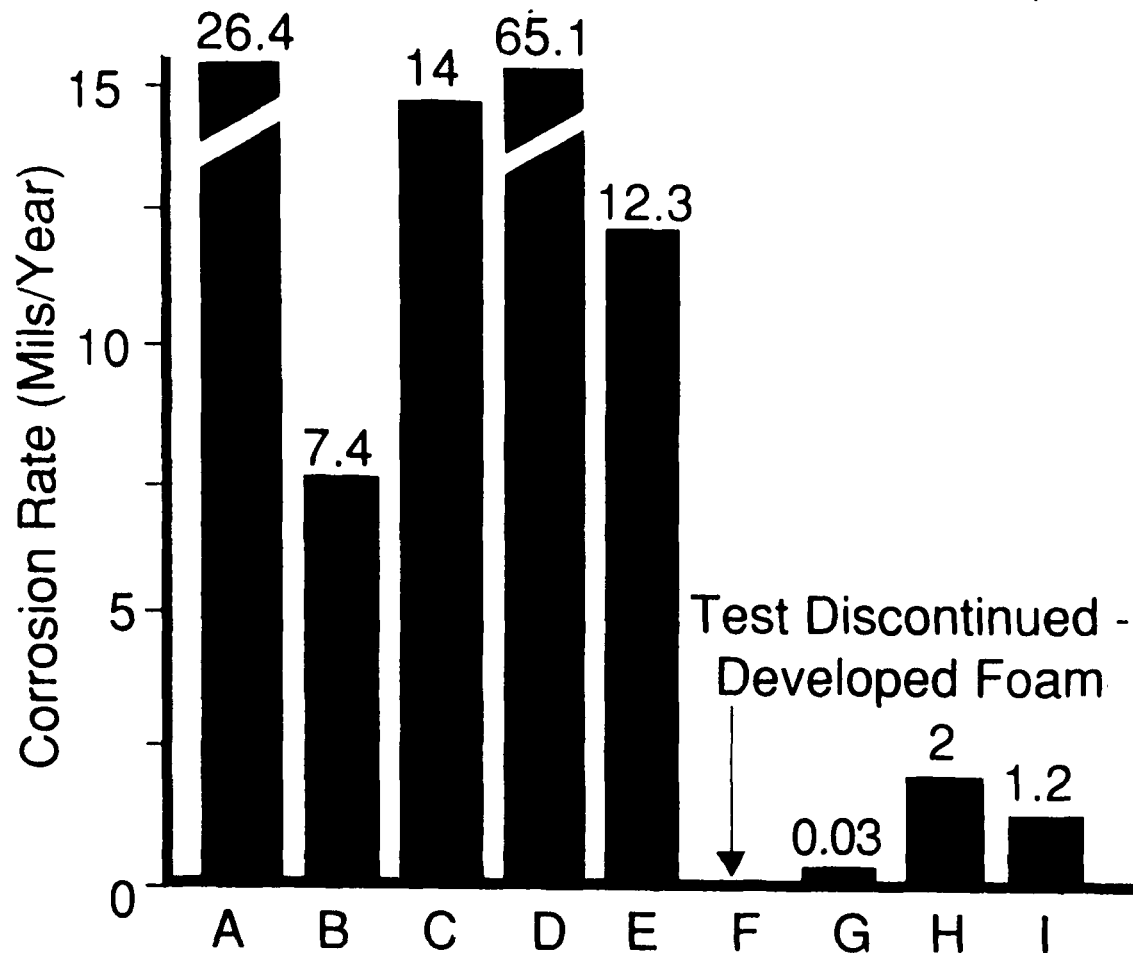
## Solution

- Solution A: 1% Sodium Carbonate
- Solution B: 1% Sodium Carbonate - Inhibitor A
- Solution C: 1% Sodium Carbonate - Inhibitor B
- Solution D: 1% Sodium Carbonate - Inhibitor C
- Solution E: 1% Sodium Carbonate - Inhibitor E
- Solution F: 1% Sodium Carbonate - Inhibitor F
- Solution G: 1% Sodium Carbonate - Inhibitor G
- Solution H: Synthetic Tap Water - ASTM D1193
- Solution I: Distilled Water

# Corrosion Inhibition

## 10% Na<sub>2</sub>CO<sub>3</sub> (Sodium Carbonate)

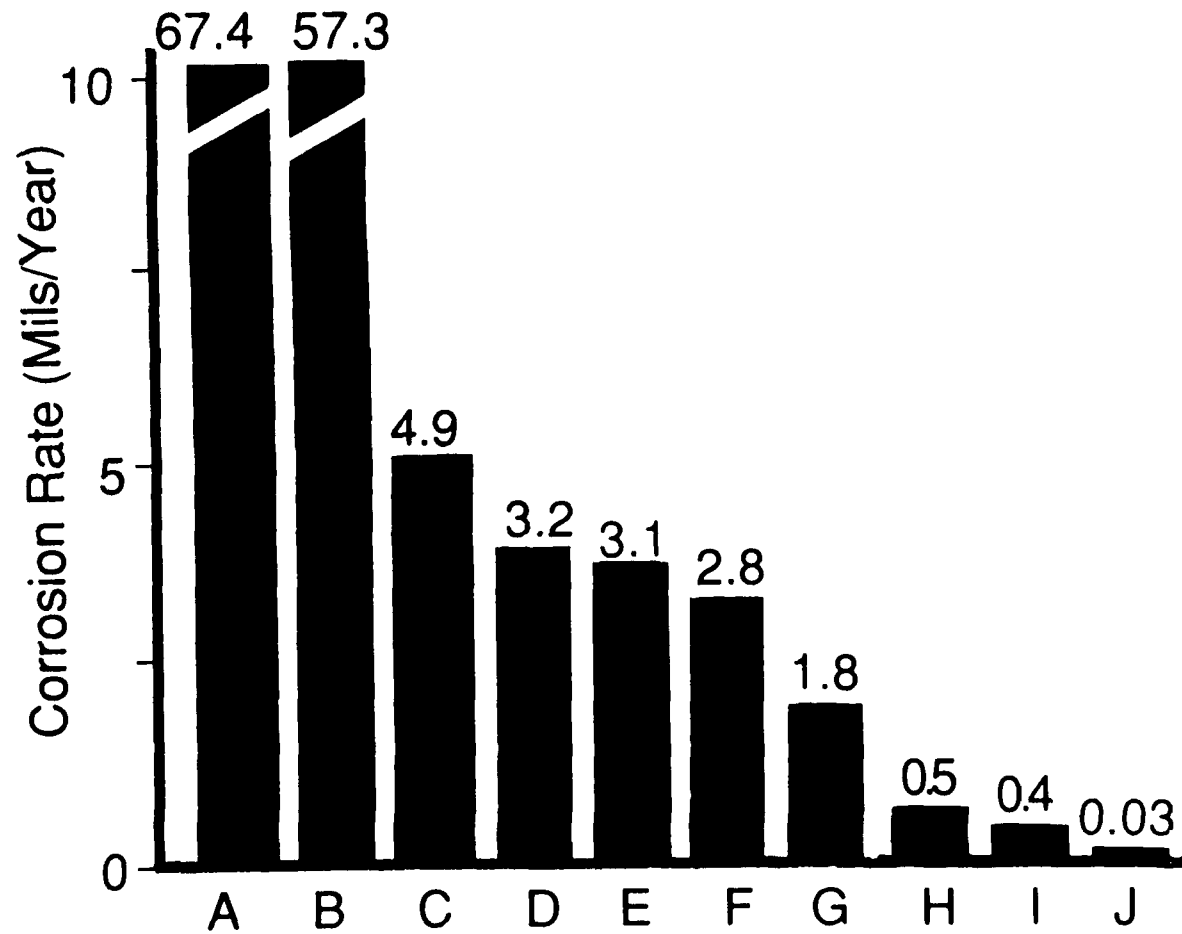
Aluminum 7075 - T6  
49°C (120°F)



Solution	
Solution A:	10% Sodium Carbonate
Solution B:	10% Sodium Carbonate + Inhibitor A
Solution C:	10% Sodium Carbonate + Inhibitor B
Solution D:	10% Sodium Carbonate + Inhibitor C
Solution E:	10% Sodium Carbonate + Inhibitor E
Solution F:	10% Sodium Carbonate + Inhibitor F
Solution G:	10% Sodium Carbonate + Inhibitor G
Solution H:	Synthetic Tap Water - ASTM D1193
Solution I:	Distilled Water

# Immersion Test Corrosion Rates

Aluminum 7075 - T6  
160°F 10 Day Exposure



## Solution

- Solution A: 1% Phosphoric Acid  
Solution B: 1% & 10% Sodium Carbonate  
Solution C: Acid Stripper  
Solution D: 2% Sodium Chloride  
Solution E: Alkaline Stripper  
Solution F: Synthetic Tap Water, ASTM D1193  
Solution G: Distilled Water  
Solution H: 1% & 10% ARMEX<sup>®</sup> Blast Media  
Solution I: 1% & 10% Sodium Carbonate + Inhibitor G  
Solution J: 1% & 10% ARMEX<sup>®</sup> Blast Media + Inhibitor G



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**ENVIRONMENTALLY ACCEPTABLE PAINT REMOVAL SYSTEMS**

Ardrox Inc. has been actively investigating the possibility of providing some new chemistry to solve an old problem - paint removal from Military and Commercial aircraft exteriors.

Over the past few years, major changes have taken place in the areas of environmental and personal health and safety issues. Although the conventional type application paint removers have for many years provided a valuable service to the Aerospace Industry, new technology is now being investigated.

All application paint removers, which are widely used throughout the industry for the removal of paint from the airframe, basically use methylene chloride as their carrier solvent. This is present at about 60-80% of the formulation. The balance of simple paint removal formulations is made up of methanol, surfactant, thickener, evaporation retarders and corrosion inhibitors. Most of the paint schemes used in our industry are not effectively removed by this simple type of formulation. For aircraft use, more powerful paint removers have been formulated using phenol or an organic acid as the activator. In some products we see both phenol and acid used jointly as the activator. An additional problem arises in the use of organic acids in that there are unfortunately, no inhibitors which can be incorporated into the formulation to stop hydrogen embrittlement of high tensile steels.

To further highlight the environmental and health and safety problems, we must realize that in using application paint removers in their present form we are evaporating large volumes of methylene chloride and other solvents into the atmosphere. Operators are also being exposed to the effects of methylene chloride, phenol and other raw materials previously mentioned as possible ingredients of the paint remover. Furthermore, large volumes of highly contaminated rinse water have to be disposed of. This not only greatly increases operational costs but is also an ongoing responsibility for the generator of this hazardous waste.

*A Formula For Excellence*

## ENVIRONMENTALLY ACCEPTABLE PAINT REMOVAL CONTINUED

When the new legislation and restrictions started to become known, the immediate reaction of the Aerospace Industry was to move away from chemicals. Many forms of mechanical means of paint removal have been presented and evaluated. Plastic Media Blasting, Solid Carbon Dioxide Blasting, Liquid Nitrogen Blasting, High Pressure Water Blasting, paint removal with Lasers plus a wide variety of blasting media, have been presented complete with engineering packages. However, to date and especially for civil aircraft paint removal, no really viable process has come to light. Problems have arisen regarding airframe manufacturer acceptance of the blasting pressures and high impact of solids which relate to possible damage to the aircraft structure. A number of questions have also been asked with regard to effective paint removal; i.e. time factors involved and surface condition prior to repainting.

During our own Research and Development meetings, we felt that there was a need for a range of chemical paint removers, which would adequately remove paint from the aircraft surface, not affect the structural integrity of the aircraft and use only raw materials which were more environmentally acceptable than methylene chloride and phenol. It was also recognized that the mechanical systems had been a very welcome alternative to hazardous chemicals. Therefore new chemistry in the form of a paint softener in conjunction with some form of mechanical action to remove the softened paint would be an acceptable compromise.

At Ardrex we set ourselves final objectives on all research programs. Sometimes these objectives were such that they could not be reached at the first attempt or over a short time period. The final criteria for this particular project was to formulate a range of neutral alkaline environmentally acceptable application paint softeners. The formulation should be classed as non-flammable and incorporate raw materials enabling rinse waters to be treated with simple (low cost) effluent treatment plants producing water which could be recirculated and reused for rinsing.

Clearly this has been a major task, but after some months of intense laboratory work, followed by evaluations with all types of mechanical removal systems, we have reached a significant stage in our research project. While we have not reached our final objective or finished our development program, we have recently provided new chemical products for evaluation at selected Aerospace locations, covering both Commercial and Military aircraft.

## ENVIRONMENTALLY ACCEPTABLE PAINT REMOVAL CONTINUED

From early results of the previously mentioned evaluations and our own internal data, we believe we are well on the way to satisfying two significant objectives that we and the industry, set as acceptable alternative paint removal procedures. Our final objective is still to produce a neutral formulation that performs like conventional (high strength) paint removers, containing no hazardous environmentally unacceptable raw materials. This may require a major joint effort in conjunction with the paint manufacturers and even a change in technology, involving both chemical removal and paint application.

Ardrox Inc. is preparing to launch a series of new products incorporating new chemistry and paint removal techniques. As previously mentioned we have two specific approaches - these being:

- A range of application paint softeners which when used in conjunction with mechanical assistance would produce a paint removal system. These products are neutral formulations containing no hazardous ingredients. Without fracturing the painted surface, they actually penetrate and swell the coating, breaking the bond. Mechanical systems can then be used for final removal. The chemical softening improves removal rates and allows lower pressures and/or soft media to be used.
- An acid activated environmentally acceptable paint remover/softener which is sufficiently active by itself to remove some paint schemes, but may also be used as a paint softener, again in conjunction with mechanical assistance on more adherent schemes.

PS:jl

REDUCING HAZARDOUS RISKS OF CHEMICAL STRIPPING  
THROUGH EFFECTIVE WASTE TREATMENT

W. L. Becktel, New Products Supervisor

Historically methylene chloride based paint strippers have been successfully used by the aircraft industry to remove the increasingly difficult paint systems that are used on commercial and military aircraft. They have been, and still are, the preferred strippers from the standpoint of ease of application, effectiveness and safety to the aircraft. However, we are now at a time when EPA (Environmental Protection Agency) regulations on disposal of hazardous wastes (which includes methylene chloride and the other activating chemicals used in chemical stripping, as well as the resulting paint residues) have become a major and costly consideration for those doing aircraft stripping.

In the past it was simply a matter of applying a stripper, allowing it to buckle and loosen the paint and then flushing the paint residues and spent stripper down the drain with copious amounts of water. However, these practices are no longer permitted by EPA and local restrictions now in place and, by even more severe ones to come. As it now stands those that are stripping aircraft with methylene chloride type strippers must adhere to the strict EPA standards on handling hazardous chemical wastes.

The currently accepted practice for handling these hazardous wastes involves the construction of plastic chutes under the aircraft to catch the paint residues and spent stripper, which are squeegeed off rather than rinsed off of the aircraft. These residues are then collected and placed in EPA approved 55 gallon drums and hauled away by a waste disposal contractor. The final rinse water must also be collected, recycled and/or treated for release to the sewer. All of this adds up to considerable increases in costs, time and labor.

In order to overcome resistance to the use of chemical strippers because of costly restrictions, an on-site waste treatment system has been developed and manufactured by Technotreat Corporation specifically for the paint stripping industry. The system is currently being marketed by McGean-Rohco, Inc. and offer the following advantages.

1. All paint sludge, solvent, chemicals and rinse water can be washed into a sump and pumped to the treatment unit. Depending upon the volume of waste water, an intermediate holding tank may be required.
2. Paint sludge can be ground in a communitor or grinder pump so that it can be pumped into the treatment unit.
3. All of the waste is then treated to remove phenol, formic acid, chromium, methylene chloride and other hazardous materials.

## Reducing Hazardous Risks of Chemical Stripping Through Effective Waste Treatment

4. The treated water and sludge, including the ground up paint flakes, are discharged to an auto indexing filter. The sludge on the disposable filter media consists of non-hazardous solids, paint chips, insoluble metallic hydroxides, dirt and grease. The volume will be in the range of 100-200 lbs. per aircraft, depending upon the weight of the paint removed.
5. The treated waste water is tested before discharge and will meet EPA standards of less than 1 mg/l phenol and chromium.
6. Some operators recycle the clean water.

This equipment is designed not only to be compatible with your preferred method of paint stripping, but will allow the maintenance crew to use the most effective strippers containing phenol and chromium. It is chemically easier, more effective and cheaper to oxidize phenol and reduce chrome in a concentrated, small volume. The hazardous chemicals are isolated and contained. They do not contaminate the entire plant treatment system. The process can be fully automatic to eliminate the need for chemically trained operators.

To comply with current EPA regulations, the hazardous wastes must be pretreated before being diluted with other plant streams flowing to the main waste water treatment system or municipal facility. Aviation maintenance waste waters often contain phenols, formic acid, ammonia, chromium, solvents, detergents and heavy metals. Most of these must be removed or neutralized. The on-site system does this in a batch process so that the chemistry can be controlled and accidental discharges prevented. Each batch is treated specifically for what it contains and is tested to be pure and safe before the cleaned water is discharged or recycled.

### Method of Treatment

- o Solvents are removed by air sparging and then catalytically oxidized. The principle solvent removed is methylene chloride. The oxidation products of methylene chloride include hydrochloric acid, which is neutralized by scrubbing with alkaline water.
- o Acid and bases are neutralized to an acceptable pH range of between 6.5 and 8.5.
- o Phenol, formic acid and other organics can be oxidized by aeration and hydrogen peroxide.
- o Chromium 6 is reduced either during treatment of the phenol or in a separate step using sodium metabisulfite, then precipitated with lime.

**Reducing Hazardous Risks of Chemical Stripping  
Through Effective Waste Treatment**

- o Heavy metals, such as cadmium, lead, copper and zinc can be removed if they are present, but additional steps may have to be added. The batch process allows for such variations in composition.
- o The treated water is filtered to remove the hazardous precipitate. Any unusual quantities or deviations from standard procedures must be identified and specific treatment designed into the system.
- o Finally, a special filter and carbon adsorbent can be used to clarify the effluent water, remove any color and adsorb minute traces of toxic materials. Ordinarily, such treatment is not required, but it provides ultimate assurance that no contaminants will remain in the industrial effluent
- o Some local regulations are so stringent, the effluent water must be nearly as pure as drinking water. In this situation, total recycle of the water is indicated, with no discharge, thereby eliminating regulation. Total recycle can be accomplished by employing a degree of special processing, such as RO (reverse osmosis) and evaporation to remove traces of soluble, but not hazardous salts that build up due to the use of city make-up water. The system is designed to remove industrial contaminants rather than produce potable or deionized water.

Typical Analysis of Waste Stream - Before and After Treatment

	<u>Before Treatment</u>	<u>After Treatment</u>
Methylene chloride...	> 100 ppm	0.03 ppm
Phenol.....	4,500 ppm	<0.10 ppm
Chromium.....	67 ppm	1.00 ppm

A Success Story

A major aircraft paint shop has been operating with this on-site system for over a year. Prior to installing this system, they were collecting and drumming up paint stripping waste for haul-away at a cost of \$486 per drum. The advantages are reflected in the comparative cost data over a nine-month period involving the treatment of fifteen (1,800 gal) batches or 2,700 gallons of stripper waste for \$865 per batch or a total cost of \$12,970.

Contract disposal costs @ \$486/drum	\$238,582.00
Disposal costs with on-site system	<u>12,975.00</u>
<b>Savings</b>	<b>\$225,607.00</b>

These data clearly demonstrate that the waste disposal costs of chemical stripping can be substantially reduced by a customized on-site disposal system, which also adds support for the continued use of the familiar and preferred methylene chloride based paint strippers.

**"PLASTIC MEDIA BLASTING - THE WISE ALTERNATIVE  
TO CHEMICAL STRIPPING"**

**Richard A. Dotson  
Vice President, Sales & Marketing  
Maxi-Blast, Inc.**

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The history of plastic media blasting is well known to many. Early in the 1980's the U. S. Air Force started investigating alternative methods of stripping aircraft under mandate by the federal government. After much research, the Air Force concluded that plastic media blasting was the most efficient and the safest way to remove paint previously removed by chemical stripping. Since this well documented introduction by the military, many industries have benefitted from this technology and knowledge now commonly referred to as plastic media blasting (PMB).

Industrial users have benefitted greatly from introducing plastic media blasting to their operations. Many users have found PBM to be the long sought after alternative to chemical stripping. The following examples will illustrate instances of successful implementation of PMB where chemical stripping was once the norm.

#### CASE STUDY 1

A Michigan custom coater had used chemical stripping for years to remove paint and residue from various metal surfaces. An official there stated, "Chemical stripping did not remove the finish completely and was not a favorite among our workers".

This company had investigated several methods of coatings removal and finally decided that plastic media was the best of the alternatives. After implementing this blast process, company officials noted that the finishing cost for 66,000 parts was reduced from .11 cents per part to less than .2 cents. In addition, some parts that were formerly sent to another company for finishing could now be dry blasted in their facility. Officials were delighted to note that without the use of chemical strippers there was no hazardous solvent with which to dispose and no on-going responsibility for toxic waste.

#### CASE STUDY NUMBER 2

A Midwestern manufacturer of wheel was faced with the problem of stripping paint from rejects while trying to stay within the EPA guidelines for chemical disposal. The chemical method of stripping used was simple: an aluminum wheel was dipped for a period of time until the paint was completely dissolved; the part was then removed, rinsed and repainted. The potential hazards of using chemicals in the method however, were high and the disposal costs were expensive. Compounding these problems were the area government officials paying particular attention to any chemical disposal methods. Finally, to make matters worse, the dip tank process was slow, requiring each wheel to soak for 4-8 hours before it could be removed and sent back to production for repainting. As the company grew and more wheels had to be stripped, the chemical process could not keep up with the accelerated growth.

Enter PMB with the appropriate equipment and media. With dry blasting, the paint coating was stripped from each wheel in 10-15 minutes with no rinsing needed afterwards. Once the blasting was completed, the wheel was reprocessed through the painting cycle and the manufacturer was more than able to keep up with rejects. In addition, EPA officials were satisfied, disposal costs disappeared and workers were relieved that dealing with chemical solvents was a thing of the past.

### CASE STUDY NUMBER 3

Another Midwestern company was faced with the problem of removing a vacuum-metallized coating from various sized paint racks. The coating was extremely tenacious and, in many cases, even chemical strippers could not successfully attack and soften the metal-coating bond. Many times paint racks were used until the coating build-up was so heavy that the only recourse was to dispose of the paint rack completely. Between the high disposal costs of the chemicals and the loss of paint racks due to inefficient cleaning processes, quite a bit of money was being spent on an operation that had become a management nightmare.

Again, plastic media solved the problem beautifully. This company purchased dry blast equipment for approximately \$14,000 and, with less than \$4,000 per month in plastic media, was able to blast clean virtually all the paint racks that had previously posed problems. Immediately the benefits were recognized. Within 3 months the investment in the equipment and media paid for itself. Company officials now saw the cleaning process as a cost savings area not a cost producing area.

### CASE STUDY NUMBER 4

In California, a custom powder coater was faced with meeting stringent EPA guidelines after having used chemical solvents for coatings removal for years. Admittedly, solvent stripping was time consuming and costly. Each part had to be soaked and scrubbed repeatedly to assure complete cleaning. The PMB process had been heard of but never tried. Although skeptical, company officials felt they had no choice but to see if plastic media would work for them.

"We found plastic media blasting to be much more efficient than chemical stripping, decreasing company labor expenses by 25-30%", noted company management. In addition, company officials recognized a remarkable increase in production efficiency and a healthier attitude among employees who were now not exposed to solvents.

What is the "hero" of all these studies? Plastic media, as was used in each of these cases, is of precisely-sized, jagged granules designed to chip away paint, coating, or residues. The plastic is available in several grades, hardness and sizes. PMB specialist can pin-point the correct media choice for almost any blasting application. See table 1.

More and more, as PMB replaces chemical stripping, former skeptics become converts. One former chemical solvent user who had been exclusively devoted to the chemical process for over eight years comments, "Plastic media stripping is the only feasible, ecologically safe way to depaint and strip products".

As for the toxic dangers involved in PMB, a leading manufacturer of plastic media states, "There is nothing in the plastic media that it considered toxic, however, any toxic paint or coating being removed might necessitate special waste handling. It is best to consult the state and local regulations to be safe". In many cases, however, the resulting "dust" can be simply thrown away.

Who are good candidates for PMB? There are many, but, in general, any company that needs to strip or clean a product and is prohibited from using chemical solvents or can't run the risk of using harsh abrasives, should consider plastic media blasting.

The conversion cost of changing from chemical stripping to PMB could actually be considered the first steps to cost savings. Depending on the part(s) to be finished, many companies require only an appropriately-sized blast cabinet, an adequate air supply and electrical power and the media itself. In many cases, companies can make this conversion for less than \$15,000 providing no additional air and electrical power is need.

Compare these costs with the cost of using solvents in most facilities. Using the Air Forces' experience with the F-4, for example, the results are dramatic. The Air Force found that once the plane was stripped using chemicals there were 20,000 gallons of contaminated water with which to dispose. Federal disposal guidelines were not lenient and workers are rarely fond of handling chemicals or breathing the fumes. Again, in this case, the time elapsed was a consideration. Typical stripping time for an F-4 was 340 hours with chemicals; 39 hours using plastic media.

In summary, PMB has much to offer the company looking for an alternative to chemical stripping.

1. Reduction, or elimination of disposal costs.
2. Time savings (labor and processing time). See Table II.
3. A healthier environment for workers.
4. A process that will satisfy most guidelines for safe handling and disposal of waste materials.
5. A reduction in the cost of materials and equipment necessary for stripping.
6. A process that will successfully strip some parts where chemicals fail.
7. Increased production efficiency.

As plastic media blastings matures and regulations continue to tighten around chemical stripping, more industrial uses will be found for this revolutionary process. Additionally, with environmental and ecological issues more important than ever to industry, the change to PMB is a logical and responsible choice. The increased use of PMB is a sensible and safe alternative not only for our world, but the individuals that inhabit it.

TABLE I

TYPES OF PLASTIC BLAST MEDIA  
AND APPLICATIONS

<u>MEDIA</u>	<u>APPLICATIONS</u>
Granulated Polyester	Extremely sensitive or thin substrates; delicate parts.
Granulated Urea	Aircraft propellers; aluminum automotive parts.
Granulated Melamine	Paint hooks and racks; office furniture; military ground transport vehicles; industrial equipment.
Granulated Acrylic	Automotive bodies (especially fiberglass); airframes; aircraft wheels and rims.

TABLE II

TIME SAVINGS, PLASTIC MEDIA BLASTING  
VS. CHEMICAL STRIPPING

	<u>PLASTIC MEDIA BLASTING</u>	<u>CHEMICAL STRIPPING</u>
Aircraft propellers	5 min.	25 min.
Automotive rims	8 min.	60 min.
Paint hooks	3 min.	20 min.
Automotive bodies	2 hrs.	2 days
Office furniture	15 min.	3.5 hrs.
Aircraft wheels	8 min.	2 hrs.
Fiberglass boats	2 hrs.	not able to strip chemically
Military ground transportation vehicles	4 hrs.	2 days

Used courtesy of Products Finishing magazine.



**SIGNIFICANT FACTORS OF MEDIA SELECTION  
FOR THE DRY STRIPPING PROCESS**

**Bob Kerr  
February 1991**

## SIGNIFICANT FACTORS OF MEDIA SELECTION FOR THE DRY PAINT STRIPPING PROCESS

The removal of coatings using plastic media in a dry stripping process has continued to gain ever-increasing acceptance and popularity. The process itself is actually a refinement entailing substantially increased precision of control of a much older and generally known type of impact finishing - abrasive blast cleaning. The first sandblast machine was designed and manufactured in Philadelphia in 1870. As the process evolved over the years, a high degree of concentration was placed on control of the variables in the abrasive blasting process with most of the concentration directed towards maximization of the kinetic energy imparted on the surface, usually with the intent of both removal of contaminants or coatings and a resultant etch for mechanical bond.

Though the objectives and application of the dry stripping process are far different from classic abrasive blast cleaning, the examination and control of the parameters of the process entails use of many of the same criteria. This is especially true with regard to the "media," or in the case of abrasive blast cleaning, the "abrasive" itself.

### CLASSIC ABRASIVES

The characteristics of abrasives evaluated for use in blast cleaning include both the physical and chemical properties of the material used. "Physical" properties evaluated include the mass, size and cleanliness, the hardness, the toughness, and the shape of the materials. "Chemical" properties evaluated vary depending upon the application but are usually directed towards degree of operator protection required and the potential of the material for contamination of the surface being blasted.

There is a distinct relationship of the properties of abrasive with the work performed. Abrasive blasting, dry stripping, or any type of impact cleaning is essentially a mechanical process. A match-up is required with all of the parameters of the process in relation to the nature of the surface to be cleaned, the nature of the desired material to be removed and the nature of the substrate.

Of course, the nature of the desired surface finish represents the end result of the application of the process.

Typical abrasives in blasting are oftentimes natural products which are quarried or processed based on selection for optimum combination of physical and chemical properties. By their nature "naturally occurring" products may take different forms from different sources, as well as different purities or variations in the properties. There may also be the presence of elements that are hazardous to the operator or the work to be performed.

Synthetic abrasives, or those that are manufactured from particular elements with the intention of maximizing the physical properties, have in the past also been subject to variations from different sources or batches. The variations, while much more controllable in a synthetic material, such as, aluminum oxide, were developed for a more primitive form of abrasive blast cleaning and are acceptable only within those fairly wide parameters.

Typically, in abrasive blasting, a user would adjust the other process variables to accommodate for variations in the abrasive most readily available to him. In fact, in some instances, subsequent processes, such as the priming or coating or bonding might have to be adjusted to accommodate the surface finish that resulted from the available abrasive.

Typically, abrasive blasting has been a relatively imprecise process with fairly wide parameters for the acceptable grades of finishes required for subsequent processes, such as coating or bonding. The direction of abrasive blasting towards satisfying its applications have, in general, been toward "minimum" standards. Design tolerances of related processes recognized these wide parameters and accommodated them.

There are exceptions to the wide tolerance levels found in classic abrasive blast cleaning. While it is a very aggressive process, it is sometimes controlled for repetitive use in more technical applications. This control, in a large part, was highly dependent on the consistency and characteristics of the abrasive employed. As a process, abrasive blasting has been used to provide the final surface finish, including satin finishes, high tolerance "clean" surfaces, or controlled peened effects on a substrate. The key to obtaining a more technically controlled finish is an absolutely predictable and repeatable combination of the parameters of the process, including the abrasive, or in the case of the dry stripping process, the media itself.

<b>ABRASIVE</b>	<b>CHEMICAL FORMULA</b>	<b>MOHS</b>	<b>PARTICAL SHAPE</b>	<b>FRACTURE</b>
Silicon Carbide	SiC	9	Angular	Uneven
Fused Alumina	Al <sub>2</sub> O <sub>3</sub>	9	Angular	Conchoidal
Natural Corundum	Al <sub>2</sub> O <sub>3</sub>	9	Angular	Conchoidal
Chilled Iron Shot/Grit	Iron with 2.85% C, 1.35% SiO <sub>2</sub> ; 0.3% Mn; 0.14% S; .004% P	8.5	Round/ Angular	Angular
Garnet	Fe <sub>3</sub> Al <sub>2</sub> (SiO <sub>4</sub> ) <sub>3</sub>	7.5-8	Angular	Uneven
Steel Shot/Wire/ Grit	Steel with 0.6-1.25% C; 0.2-1.1% SiO <sub>2</sub> ; 1.25% max Mn; 0.08% S; 0.08% P	7-8	Round/ Angular	Angular
Staurolite	MgFeAl Silicate	7-7.5	Rounded	Conchoidal
Silica/Sand Quartz/Flint	SiO <sub>2</sub>	7	Round/ Angular	Angular
Metallic Slag Cu	32-45% SiO <sub>2</sub> ; 25-33% CaO + MgO; 24-35% FeO	6-7	Angular	Angular
Pb	28-37% SiO <sub>2</sub> ; 16-21% CaO + MgO; 30-45% FeO			
Olivine	(MgFe) <sub>2</sub> SiO <sub>4</sub>	6-7	Angular	Conchoidal
Glass Beads	Soda-lime glass	5-5.5	Spherical	Angular
Plastic Media	Polyester Urea Formaldehyde Acrylic Melamine	3-4	Angular	Angular

**Figure 1. ABRASIVES COMMONLY USED IN IMPACT FINISHING**

## PLASTIC MEDIA

Plastic media used in the dry stripping process is probably the most synthetic and, therefore, controllable material used in impact cleaning. The material is referred to as media, in general, because it does not have the severe "abrasive" characteristics of materials used in conventional abrasive blast cleaning. The material is specifically designed within very tight tolerances to produce a much less aggressive effect than blast cleaning. A comparison of the generally available plastic medias with conventional abrasives in Figure 1 highlights the much "softer" nature of the material on the Moh scale due to the much higher concern for retaining the integrity of the substrate. In fact, the other materials evaluated in Figure 1 would, without exception, be considered serious contaminants if found in plastic media.

The plastic medias currently used in the dry stripping process are manufactured from cured polymer resins. Initially, thermosets such as polyesters and urea polymers were used. However, as newer applications and user techniques have expanded, so have the range of media base polymers. Important to the media quality is the tight control of the polymer characteristics during manufacture. The manufacturing process concentrates on producing the optimum combination of physical properties in an essentially neutral chemical particle.

## PHYSICAL PROPERTIES

### THE MASS OF THE MEDIA:

Plastic media has a bulk density of 40 to 57 lbs. per cubic foot, with a specific gravity in the range of 1.15 to 1.50. In rough comparison to the abrasives shown in Figure 1, silica sand has a mass of about 100 lbs. per cubic foot, while the steel grit has a mass of about 250 lbs. per cubic foot. As the process entails the imparting of kinetic energy to the surface in a controlled fashion, this lighter mass is a key factor in producing the "non-aggressive" effects desired in the dry stripping process. This mass is also controllable in the manufacturing process by the media supplier. With the low velocities used in the dry stripping process (due to the lower operating pressures employed when compared to conventional abrasive blasting), the impact force should be controlled to affect and remove only the desired coating layer or layers with minimal ancillary effect.

### THE SIZE AND CLEANLINESS

The size and cleanliness of the media as a physical property, also affect the impact cleaning. With a fixed mass mentioned above, size can, within a certain range, determine impact force and degree

of penetration in the coatings. Size is also a key factor in producing the physical characteristics of the finished surface, including evaluation for depth of penetration, if any. Size, also as a characteristic, entails cleanliness. Cleanliness examines for the presence of undersized material as an indication of the quality control employed in the manufactured process. Media size is normally a mix, or range, of screen sizes that can be as tight or broad as necessary. In addition, the mix of sizes can be effected by actual blending of various size materials (of the same hardness) in different percentages to obtain a working mix. In either case, proper quality control would not allow for the inclusion of any significant levels of fines or undersized material (outside specified parameters for that mix size). Fines do not aid the process. They only produce unnecessary dust and take up valuable space in the air stream during the media propulsion.

### HARDNESS

Hardness is, as mentioned above, one of the key aspects of differentiation of plastic "media" from the general category of "abrasive." Plastic media is generally currently available in three basic hardnesses on the Moh scale (1) of 3.0, 3.5, and 4.0. The 3.5 media, with its mid-range hardness has the broadest field of applications. The hardness factor is a matchup to the coating to be removed as well as the substrate characteristics. Generally, hardness is not a "mixed" result. While various sizes may be blended to working mix, most users prefer specific, consistent hardness characteristics. Each particle ideally would be of identical hardness to the other particles in the media. Hardness within a certain range is a function of the controls employed in the manufacturing process.

#### MOH HARDNESS

TALC	1
ALUMINUM	2 TO 2.9
COPPER	2.5 TO 2.9
BLACK WALNUT SHELLS	2.9
PLASTIC MEDIA	3.0 TO 4.0
CORN COBS	4.5
IRON	4 TO 5
GLASS	4.5 TO 6.5
APATITE	5
STEEL	5 TO 8.5

Figure 2. MOH Hardness Table

## TOUGHNESS

Toughness is a phrase generally employed in relation to abrasives to indicate their "non-friability" or resistance to breakdown of the media to particle sizes outside the range of the desired mesh size of the working mix. Toughness is a characteristic related to hardness in a general sense in that harder materials are normally more brittle. In synthetic abrasives or media, however, other elements can be included to provide for a more resilient particle while still maintaining appropriate surface hardness and angularity.

Toughness is also difficult to measure. A "shatter" index exists for some manufactured abrasives. This is really an indication of the number of particles created by the impact of a known force on a predetermined number of particles. The actual importance of the toughness of the media and, therefore, the only realistic measure of the toughness is the percentage of breakdown to a particle size outside the desired parameters in actual use.

Friability may also be an indicator of inconsistency of the material. If, for instance, different types of resins are mixed, particle segregation can take place.

In general, plastic media has an attrition rate of 5% to 10% per application. This attrition rate is a function of both the toughness of the media itself, as well as the efficiency of the cleaning and reclassification equipment. Also important is the thoroughness of the recovery process.

## SHAPE

The shape of the plastic media most successfully employed in the dry stripping process is angular. While several synthetic media exists that are extruded in various shapes for particular electronics applications, an irregular angular shape similar to that found in conventional abrasives, has proved most successful in dry stripping on sensitive surfaces. The shape of the resultant impact fracture of the media is also important, and, in the case of plastic media, the fact that the resultant fractured grain of media is also angular, provides for consistent reuse with predictable finish results.

## CHEMICAL PROPERTIES

The chemical properties in plastic media are not a positive contributor to the process, therefore are ideally neutral. Plastic media is essentially inert and there is no change in reactivity due to accidental contact with other materials. It is also zero percent volatile by volume and not a combustion hazard. Several

minimum Explosive Concentration Tests have been run on the various medias with results indicating that the medias require very high concentration of very fine particles before posing any type of explosive hazard.

A characteristic peculiar to plastic media which has been so carefully synthesized is consistency in color of the particle. Consistency as a result of production methods and care can provide the desired combination of physical properties mentioned above from one particle to the next in a specific batch and from batch to batch of a specific grade of media. If desired, a specific color can be provided for ease in identification, if different types of media are being stocked by a user. The color also helps highlight contrasting contaminant colors as a visual check on the efficiency of cleaning of the media in recycling for reuse. Color can also provide a visual check of surface for residual dust for the wash-down procedure.

### PROPERTIES OF PLASTIC MEDIA

#### PHYSICAL PROPERTIES

- . Mass
- . Size and Cleanliness
- . Hardness
- . Toughness
- . Shape
- . Consistency

#### CHEMICAL PROPERTIES

- . Consistency
- . Contamination
- . As Appropriate for Operator Safety
- . As Appropriate for Environmental Protection
- . As Appropriate for Application and Workpiece  
(Surface or Substrate Contamination or Reaction)

Figure 3. Properties for Evaluation of Plastic Media

## PRECISION CONTROLLED MANUFACTURE

The phrase "controllable in the manufacturing process" was used repeatedly in the evaluation of the characteristics of the plastic media. Unlike sourcing naturally occurring abrasives, the production of, and hence the control of the variables of plastic media, should be a very precise process. Though the manufacturing process and actual compounds of any supplier of this type of material is maintained as a trade secret, several process variables are critical to the adherence to tight tolerances between batches and between particles within a batch of the finished product. This consistence, therefore, does affect the predicted repeatability of the stripping process.

Electron microscope scans are used to evaluate the elements of the material for both the presence of undesirable elements and for consistency of compounding. No heavy metals, such as chromium, found in some pigments, should be present.

Two basic sources of raw material are used in the manufacture of media. Discard materials from molders and/or virgin resins/compounds. Theoretically, discard moulded material can be used to manufacture acceptable quality media if the discard molded material is of properly specified compounds and are properly and completely cured. Consistent media quality is, however, at risk, even when very close and frequent checks are made to the discard molded material. Both the presence of contaminants and incomplete compound cure are difficult to detect in discard material.

Use of virgin compounds/resins on the other hand offer substantial control over quality and consistency, particularly when moulding process is performed at the manufacturers plant.

Plastic synthetic media has, by the nature of the controlled manufacturing process, a unique ability allowing for the variance of the specification requirements within certain parameters in response to user needs. As the dry stripping process has been developed, the critical aspects of properties of the media have also been refined. Only a "manufactured media" can respond to these evolving requirements and the continually evolving specifications of this process.

When users advised that the presence of any metallic particles might adversely affect the surface, a manufactured media could be adjusted to eliminate this material. Presence of such foreign materials and their ability to impregnate in the substrate is clearly seen by examination of the non-plastic abrasives in Figure 1 discussed above.

When it became apparent that some users felt concern about the neutrality or alkalinity (pH) of the media, a manufactured media could be modified to confine the neutrality within a specific pi-hydron range.

When users requested a media of a single "contrasting" color to assist in identifying the presence of contaminants in material for reuse, and the presence of residual dust during removal and washdown, a manufactured media could respond cooperatively to this request.

Hardness can be varied to suit (within a certain range) and then reproduced repeatedly with a manufactured plastic media. Size can be controlled and provided batch to batch with a quality control possible only in manufactured media. Shape, mass, almost any variable could be controlled within certain parameters and produced repeatedly in a manufactured plastic media.

"Precision control" of such an absolutely critical variable as the media in the dry stripping process through careful, consistent, production of a synthetic material is the only logical approach to obtaining the level of confidence necessary to repeatedly employ the dry stripping process. Grumman Aircraft, in their test program of the process, concentrated significant effort in evaluation of the media. Their report takes great care to point out the implications of indications of contamination through the presence of sulphur chlorine and lead contaminants, as well as composition inconsistencies and the unknown effect this might have on the consistent application of the process.

The process itself has a series of typical work requirements that must be addressed and, in part, these requirements are addressed through the matchup with the appropriate media. A typical stripping job entails the removal of a coating or contaminant, such as carbon, perhaps with selective layer-by-layer control of the removal process. It is critical, generally, to maintain the integrity of the substrate protecting against excessive material removal, or change in the substrate physical properties, such as, through peening or fiber damage. Also required is protection from impregnation or intrusion into the substrate with foreign particles.

Use of the dry stripping process also satisfies work requirements not related to the surface itself, but more to considerations of the operator, the environment, and the economics and productivity of coating removal. With plastic media stripping there is a reduction in the requirement for neutralization of toxic materials and their disposal, considerably improved production rates, substantial operator visual inspection, and a reduction in the operator's exposure to hazardous work.

In addition, dry stripping provides for the ability to vary the process to match specific surface conditions and finish requirements. The increased use of composite materials and the differences in their surface properties can only be consistently addressed by varying the parameters of the dry stripping process to suit a particular new material.

As development, evolution, and precision control of the dry stripping process continues, there is a strong indication that this is the only method that can be expected to keep pace with the rapid advancements in aircraft materials that we can expect in the future.

**NON-METHYLENE CHLORIDE PAINT REMOVERS  
BASED ON N-METHYL-2-PYRROLIDONE (NMP) AND  
THICKENED WITH ETHYLHYDROXYETHYLCELLULOSE (EHEC)**

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**ABSTRACT**

Paint removers based on N-methyl-2-pyrrolidone (NMP) in combination with propylene glycol methyl ether acetate and mineral spirits were prepared and tested for effectiveness on a variety of coatings versus commercial paint removers. Typical polymeric thickeners such as hydroxypropylcellulose (HPC) and methylhydroxypropylcellulose (MHPC) were not soluble in the experimental solvent formulations. Ethylcellulose (EC) and ethylhydroxyethylcellulose (EHEC) were soluble. EHEC was used to thicken the experimental paint remover formulations because of its greater efficiency. The experimental NMP-based paint removers generally performed well relative to a methylene chloride-based paint remover and non-methylene chloride paint removers.

## INTRODUCTION

Concerns about the health and environmental effects of methylene chloride have prompted interest in alternative solvents for paint removers. N-methyl-2-pyrrolidone (NMP) is an attractive alternative solvent because of its low toxicity, low evaporation rate, high flash point and good solvency. However, the relatively high cost of NMP requires it to be diluted with other solvents in order to obtain reasonable economy. Polar solvents such as alcohols and ketones tend to reduce the effectiveness of NMP when used as diluents [1]. Aromatic hydrocarbons, on the other hand, have been found to improve effectiveness while providing economical dilution [1,2]. Ternary blends of NMP, glycol ether ester and aromatic or aliphatic hydrocarbons have also been demonstrated to be effective paint removers [1]. In the case of combinations of NMP with aliphatic hydrocarbons, the third solvent such as propylene glycol methyl ether acetate (PM acetate) must be included to effect solution because NMP is not miscible in aliphatic hydrocarbons.

Modified cellulosic polymers are commonly used to thicken methylene chloride-based paint removers [3,4] and have been used successfully to thicken NMP-based paint removers. Ethylcellulose (EC) and hydroxypropylcellulose (HPC) are reported to be effective thickeners for combinations of NMP and aromatic hydrocarbons [2,5]. Methylhydroxypropylcellulose (MHPC) is reported to be effective in a combination of NMP, aromatic hydrocarbon and benzyl alcohol [6]. However, in a solvent system composed of NMP, glycol ether ester and large amounts of aliphatic hydrocarbon, the traditional cellulosic thickeners would not be expected to be effective because of their lack of solubility in aliphatic hydrocarbons. Ethylhydroxyethylcellulose (EHEC), though, should be an effective thickener for such a solvent system because of its high tolerance for aliphatic hydrocarbons.

The purpose of this research was to identify polymeric thickeners for a paint remover based on a combination of NMP, PM acetate and mineral spirits and to evaluate the thickened paint remover versus commercial products based on methylene chloride and alternative solvent systems.

## EXPERIMENTAL

The materials used in the experimental paint remover formulations are listed in Table 1. Four modified cellulosic polymers were tested for solubility in the combination of 30:40:30 parts by weight of NMP:PM acetate:mineral spirits. Two types of mineral spirits (MS) were tested: a regular grade (Sun T) containing 18% aromatics, and an odorless grade (Shell Sol 71) which contains less than 0.1% aromatics.

Solution properties are listed in Table 2. Only EC and EHEC were soluble in these two solvent systems, and the EC solution containing odorless mineral spirits was very hazy, indicating borderline solubility. Viscosities were measured at 23 °C (73 °F) using a Brookfield LV viscometer and a #2 spindle at 12 rpm. EHEC XX High displayed better thickening efficiency than EC T-350 and was thus chosen as the thickener for the two experimental paint removers based on these solvent systems. The compositions and physical properties of the two experimental paint remover formulations are listed in Table 3.

Five generic coating types were selected for the paint remover evaluations (Table 4). These coatings were applied to wood and metal panels to form the coating/substrate systems listed in Table 5. The latex paint on pine wood was at least six years old. The nitrocellulose furniture lacquer was a formulation of 40:50:10 parts by weight nitrocellulose:alkyd resin:plasticizer. The commercial alkyd, epoxy and two-component urethane paints were applied to Bonderite Spra 100 zinc phosphate-coated steel panels from Parker-Amchem and were cured according to the paint manufacturers' instructions. The cured paints were tested by methyl ethyl ketone (MEK) double-rub testing for completeness of cure with the results also shown in Table 5.

Three commercial paint removers were selected as controls for the performance evaluation. These commercial paint removers were based on the solvent systems described in Table 6.

The paint remover evaluations were conducted by pouring approximately three milliliters of paint remover onto each coating and measuring the time for the coating to lift or to soften to the point where it could easily be scraped off with a putty knife.

#### DISCUSSION OF RESULTS

The experimental paint removers based on NMP gave performance equal to the methylene chloride-based commercial control on latex paint and were slightly faster to soften furniture lacquer, although all of the paint removers tested softened these two thermoplastic coatings in only a few minutes. Test results are presented in Table 7. The latex and lacquer softened and remained in complete contact with the wood substrates (did not lift) under the action of all of the paint removers, and thus only time-to-soften was measured for these coatings.

The alkyd paint was lifted by all of the paint removers--very quickly by all except the dibasic esters-based control--and thus only time-to-lift was measured for this coating.

Although the experimental NMP-based formulations did not lift the epoxy or the urethane, they softened the epoxy quickly and softened the urethane faster than the dibasic esters-based control. The methylene chloride-based control lifted the urethane paint very quickly and lifted the epoxy primer in reasonably short order. The methanol/toluene/acetone-based commercial control softened both the epoxy and urethane quickly but needed more than eight hours (overnight) to lift these two coatings. For the epoxy primer and the two-package urethane, both time-to-soften and time-to-lift (if lifting occurred) were measured with the exception of the methylene chloride-based remover on the urethane paint, which lifted too quickly to measure time-to-soften.

The experimental NMP-based formulations and the dibasic esters-based commercial remover tended to keep the coatings soft for very long times (48 hours or more) compared to the methylene chloride- and methanol/toluene/acetone-based controls. This advantage is the result of the very low volatility of NMP and dibasic esters. Paint removers based on these solvents do not need evaporation inhibitors.

The odorless mineral spirits in experimental Formulation #2 had the advantage of giving a flash point over 100 °F. Slightly longer times were required by this formulation versus regular mineral spirits to soften some of the coatings, but the ultimate effects on the various coatings by the two experimental formulations were the same.

The flash points of both experimental paint remover formulations were unexpectedly low. The component with the lowest flash point in Formulation #1 is the regular mineral spirits at 103 °F, but the composition flashed at 89 °F. In Formulation #2, the PM acetate has the lowest flash point (116 °F), and the odorless mineral spirits has a flash point of 125 °F, but the composition flashed at 102 °F. The flash point of NMP is 199 °F. These results indicate that the combination of NMP, PM acetate and mineral spirits exhibits a negative azeotrope [7] and that the choice of mineral spirits will determine the flash point of such a mixture.

## CONCLUSIONS

Paint removers based on NMP diluted with PM acetate and mineral spirits can be effectively thickened with EHEC XX High. Such paint removers performed favorably relative to commercial methylene chloride-free paint removers tested that were based on alternative solvents other than NMP. The NMP-based paint removers performed favorably relative to a commercial methylene chloride-based paint remover on thermoplastic coatings and on a thermoset alkyd, but were not as effective as the methylene chloride-based product on two other thermoset coatings. The NMP-based paint removers do not require an evaporation retarder and have the advantage of keeping coatings soft for much longer periods of time than methylene chloride and highly-volatile alternative solvents. The NMP-based formulations have the advantage of reduced flammability over commercial products based on combinations of methanol, toluene and acetone.

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**Table 1  
Paint Remover Raw Materials**

<b>Material/Supplier</b>
EC T-350 Ethylcellulose (EC) Aqualon Company
EHEC XX High Ethylhydroxyethylcellulose (EHEC) Aqualon Company
Klucel®-H PR Hydroxypropylcellulose (HPC) Aqualon Company
Culminal® MHPC 20,000 S Methylhydroxypropylcellulose (MHPC) Aqualon Company
N-Methyl-2-pyrrolidone (NMP) BASF Corporation
Propylene glycol methyl ether acetate (PM acetate) Arco Chemical Company
Sun T regular mineral spirits Sun Company
Shell Sol 71 odorless mineral spirits Shell Chemical Company

**Table 2  
Solution Properties of Modified Cellulosic Polymers  
in 30:40:30 NMP:PM Acetate:Mineral Spirits**

<b>Polymer</b>	<b>Concentration, Parts per 100 Parts Solvent</b>	<b>Viscosity, mPa·s (cps)</b>	
		<b>Regular MS</b>	<b>Odorless MS</b>
EC	6.0	1,010	1,080
EHEC	4.0	955	860
HPC	0.5	Insoluble	Insoluble
MHPC	0.8	Insoluble	Insoluble

**Table 3**  
**Experimental NMP-Based Paint Remover Formulations**

<u>Formulation</u>	<u>Parts by Weight</u>	
	<u>1</u>	<u>2</u>
NMP	30	30
PM acetate	40	40
Regular mineral spirits	30	-
Odorless mineral spirits	-	30
EHEC XX High	4	4
Total weight	104	104
<u>Properties</u>		
Viscosity, mPa•s (cps)	955	860
Density, g/L	920	905
lb/gal	7.7	7.5
Flash point,		
Tag closed cup, °C	32	39
°F	89	102
Solution quality	Water White, Slightly Hazy	

**Table 4**  
**Coatings Used in Paint Remover Evaluations**

<u>Coating</u>	<u>Description</u>
Latex Paint	Unknown gray latex paint.
Furniture Lacquer	Nitrocellulose lacquer.
Alkyd Paint	Benjamin Moore Impervo alkyd enamel #133-5A TG-4X8, WH-2X, aqua green
Epoxy Primer	PPG DP-40 epoxy primer, olive green
Two-Package Urethane	PPG Durethane polyester-urethane enamel, black

**Table 5  
Coating/Substrate Systems**

<u>Coating</u>	<u>Substrate</u>	<u>Dry-Film Thickness, Mils</u>	<u>Solvent Resistance, MEK Rubs</u>
Latex	Solid White Pine	2-5	No Test
Lacquer	Birch-Veneer Plywood	2.0-2.2	No Test
Alkyd	Bonderite Spra 100	1.2-1.5	60, Film Broke
Epoxy	Bonderite Spra 100	1.0-1.2	200, Dulling
Urethane	Bonderite Spra 100	1.3-1.7	200, No Effect

**Table 6  
Paint Removers Evaluated**

<u>Paint Remover</u>	<u>Solvent Composition</u>
Commercial #1	Methylene Chloride/Methanol
Commercial #2	Methanol/Toluene/Acetone
Commercial #3	Dibasic Esters
Experimental #1	NMP/PM Acetate/Regular Mineral Spirits
Experimental #2	NMP/PM Acetate/Odorless Mineral Spirits

**Table 7  
Paint Remover Comparison**

Time to Soften (S) and/or Time to Lift (L)  
in Minutes Unless Overnight (ON)

<u>Paint Remover</u>	<u>Latex Paint</u>	<u>Furniture Lacquer</u>	<u>Alkyd Paint</u>	<u>Epoxy Primer</u>	<u>Two-Pack Urethane</u>
Commercial #1	1(S)	6(S)	1(L)	1(S)/27(L)	-/1(L)
Commercial #2	1(S)	1(S)	1(L)	2(S)/ON(L)	5(S)/ON(L)
Commercial #3	4(S)	5(S)	46(L)	13(S)/ON(L)	45(S)/-
Experimental #1	1(S)	1(S)	3(L)	4(S)/-	15(S)/-
Experimental #2	1(S)	2(S)	4(L)	4(S)/-	20(S)/-

# Solvent Recovery Using the Brayton Cycle Heat Pump

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## Abstract

A progression of designs to control volatile organic compound (VOC) emission streams using a reverse Brayton cycle are described in this paper. An advanced design, soon to be built, is the result of an intensive cooperative effort of 3M, Nucon International and the U.S. Department of Energy (DOE) over the last two years. The new advanced design benefited from a development effort started by 3M in 1975. Similarly, Nucon and the U.S. DOE have been involved with 3M since the early 1980's in the development of the Brayton Cycle Heat Pump (BCHP) for solvent recovery, recycle and reuse. The technical performance along with the estimated costs of an 8000 SCFM BCHP (that is used in conjunction with solvent concentrating adsorption beds) at a 3M manufacturing plant is detailed.

## Introduction

The use of solvents in industry is widespread. Solvent use affects a large cross-section of products such as adhesive tape, plastic foams, synthetic fibers, electronic components, furniture manufacture and many more. Recently, environmental concerns have prompted stricter legislation to control VOC emissions (i.e. The Clean Air Act). At the same time the price of some solvents has increased significantly forcing industry to search for cost effective alternatives to manufacture profitably yet within environmental regulations. Industry is thus presented with the following choices:

- 1) Eliminate the need for solvents in the manufacture of their product.
- 2) Reduce VOCs by making the process "tighter" (i.e. prevent fugitive emissions).
- 3) Control VOCs by incineration or destruction.
- 4) Control VOCs by capturing and recycling them back to reusable solvent.

3M uses solvents to manufacture a variety of products (eg. adhesive tape, magnetic tape or discs, and other products requiring coating). A corporate wide effort has been implemented by the top management to reduce VOC emissions by 90 percent by the year 2000. Therefore, all of the four choices above are being considered.

Controlling VOCs by capture on activated carbon adsorption beds is common in industry today. Although the number of solvent control devices number in the thousands in the U.S., the level of VOCs that are uncontrolled is by far greater. The U.S. DOE recognizes the expanse of solvent recycling throughout the nation as an opportunity to save a significant amount of energy (50 trillion BTUs annually valued at over 200 million dollars). This energy savings will result from more energy efficient VOC control equipment to be brought to the marketplace and the saving of the embodied energy of the solvent (i.e. the aggregate of the process energy and feedstock fuel heating value energy required to manufacture the solvent is the embodied energy).

### DOE Project Objectives and Goals

There are two main goals of this project:

Goal 1 The first goal is to demonstrate economic solvent recovery for large VOC emission points (e.g. a 1000 ton per year VOC source). A payback of less than three years based on the total installed cost of the equipment with solvents moderately priced at 30 cents per pound, independent of environmental regulatory costs, is a target that DOE and 3M want to achieve.

Goal 2 The second goal is directed at small solvent users of less than 500 tons per year. The mobile BHP should demonstrate to small solvent users (100 tons per year on average) that the annualized costs of this technology can control many different types of VOC sources at under \$1000 per ton.

Of course, these two goals must be achieved concurrent with reliable equipment, energy efficient equipment and equipment able to meet environmental regulations.

### DOE Project Application Areas

#### The Large VOC Control Application

3M and the U.S. DOE are working cooperatively to develop an advanced BHP system. DOE will fund 3M (on a cost sharing basis) to design, manufacture and field test an 8000 SCFM BHP system that will be installed at the 3M Greenville, SC manufacturing plant to control a 1000 ton per year VOC emission source. Nucon International of Columbus, Ohio, is assisting 3M on this project by providing process engineering, equipment design and, manufacture and installation of the packaged BHP regeneration/VOC adsorption system.

#### The Small VOC Control Application

The Greenville plant application is a relatively large VOC control application. VOC emission source greater than 500 tons per year probably accounts for less than 10 percent of the total VOC emissions. Therefore, DOE will cooperatively work with Nucon International to cost effectively develop a BHP to control small VOC emission points (e.g. less than 500 tons per year). This project will mobilize the BHP and thus allow a single mobile BHP system to regenerate numerous concentration beds at scattered industrial host site locations. In this way the capital cost of the mobile BHP (estimated at \$300,000 to \$400,000) can be distributed amongst many industrial

solvent users. Southern California Edison (SCE) and The Electric Power Research Institute (EPRI) are co-sponsoring this project with Nucon, 3M and the DOE, and therefore, the host sites will be located in the Southern California area. Figure 1 shows the small mobile BCHP system that will initially be demonstrated to four companies in Southern California. Applicability of the Brayton concept in solving their specific VOC recovery problem will be evaluated.

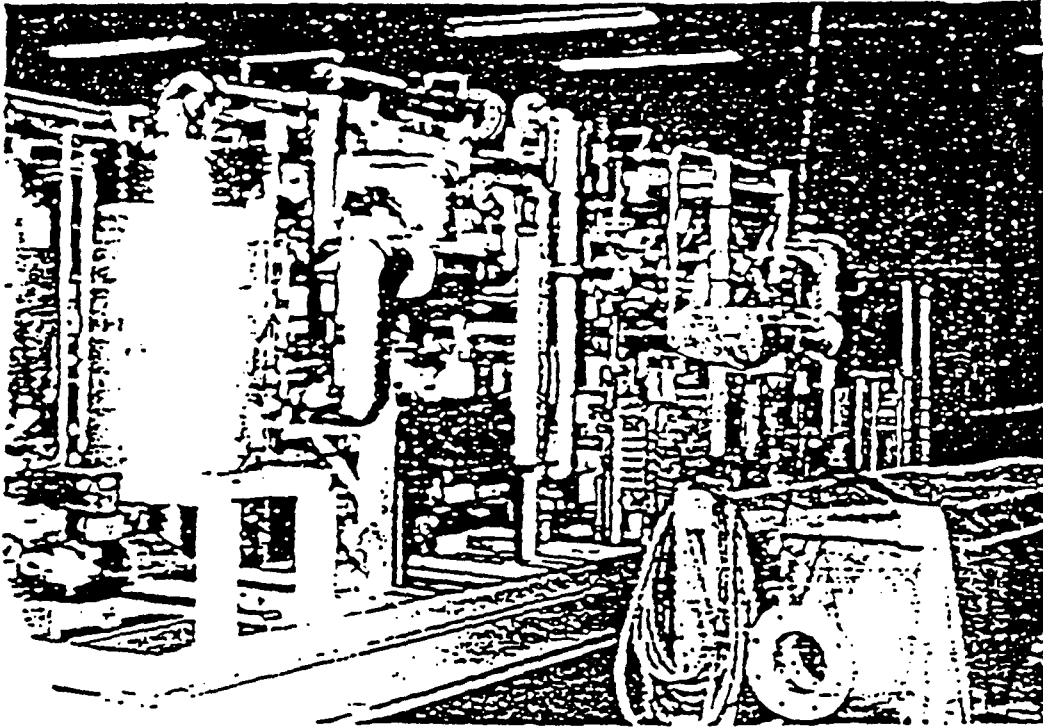


Figure 1 - Small Mobile Brayton Cycle Heat Pump System

### Description of the Brayton Cycle

The BCHP is an alternative means of condensing solvents from a gas stream by use of a reverse Brayton cycle. Many solvent streams must be refrigerated to temperatures below  $-50^{\circ}\text{F}$  ( $-45^{\circ}\text{C}$ ) to condense greater than 90 percent of the solvent in a single pass through the condensing system. Other refrigeration methods, such as a reverse Rankine cycle using refrigerants in a closed cycle loop can be and have been used to condense solvents to these low temperatures. (Comparison of the Brayton cycle to the Rankine cycle will be given later).

To illustrate how refrigeration is accomplished with the reverse Brayton cycle, Figure 2 shows an ideal regenerative reverse Brayton cycle on a temperature/entropy diagram. At station 1 the solvent laden gas stream is compressed isentropically to station 2. Heat is extracted in the regenerator from station 2 to 3 at constant pressure. Because heat is extracted from station 2 to 3 the cycle is termed a reverse Brayton cycle. If heat was added by heat exchange or combustion (such as in a gas turbine power plant or jet engine), then the cycle would be a forward Brayton cycle. At station 3 the gas stream temperature will be cold enough to condense a majority of the solvents. From station 3 to 4 the gas stream has work extracted isentropically in an expander (turbine) to lower the gas stream temperature even further. (Temperatures as low as  $-150^{\circ}\text{F}$  ( $-101^{\circ}\text{C}$ ) can be achieved in a single stage of compression and expansion). Essentially all of the remaining solvents are condensed at station 4. The work produced by the expander partially drives the compressor. The remainder of the compressor work requirement comes from mechanical shaft work input. The cold gases at station 4 are then passed through the other side of the regenerator to recoup heat at constant pressure to complete the cycle.

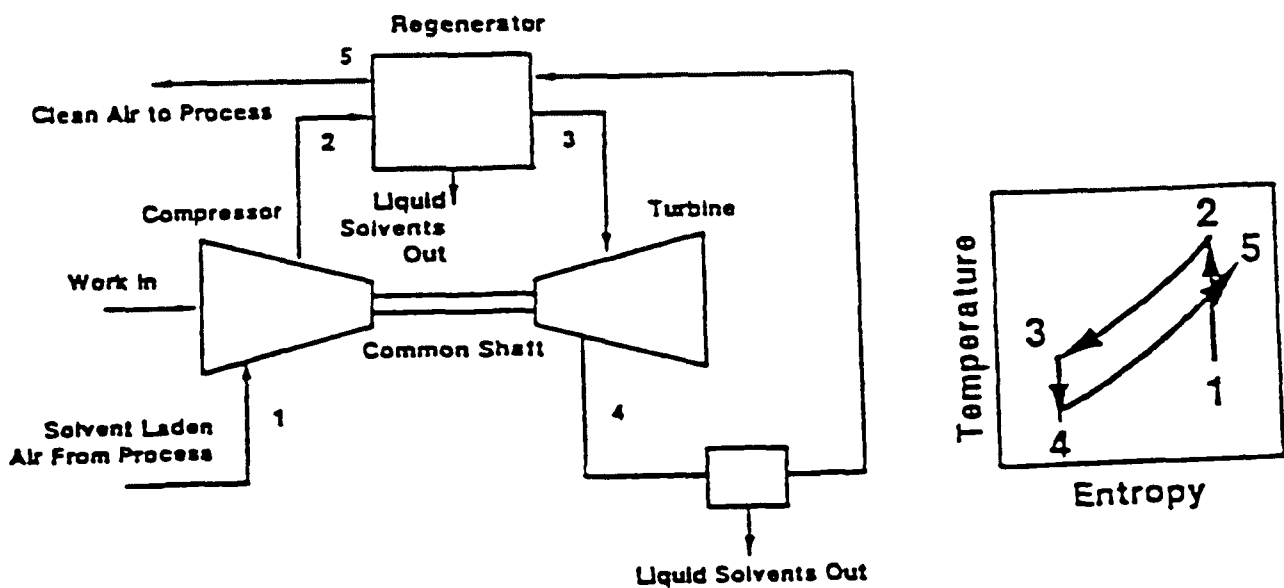


Figure 2 - Description of the Reverse Brayton Cycle with Solvent Recovery

Although the Brayton cycle requires high speed turbomachinery, this machinery is commonly used today. All air conditioning systems used on commercial and military jet aircraft use a reverse Brayton cycle system. For aircraft applications, the Brayton refrigeration method has been selected for reasons of low weight and high reliability. Another application of the reverse Brayton cycle is a cryogenic air separation plants. Here too, reliability has been good for over fifty years. At present, the most common application of the Brayton cycle is the automotive turbocharger.

### Project Background

As mentioned, 3M has actively pursued the BCHP for the past 15 years. Bryce Fox (a retired 3M engineer) was the champion of this technology and is named sole or joint inventor on three 3M patents. (1), (2), (3)

In 1979 3M funded the AiResearch Manufacturing Company (a division of the Garrett Corporation) to provide a 2000 SCFM prototype Brayton cycle system. This was used to process a solvent laden gas stream from an inert gas drier at 3M. In showing feasibility and successful operation of this system, the U.S. DOE decided to fund a larger 9000 SCFM unit that was installed at 3M's Hutchinson, MN tape manufacturing plant. Both of these systems directly condense the solvents by processing the solvent laden air (SLA) from the coating process through the BCHP.

Both the 2000 and 9000 SCFM system designed by AiResearch used specially manufactured gear boxes that were costly. The system installed at the Hutchinson plant (see Figure 3) shows the gear box coupling the input shaft power (an electric motor running at 3600 RPM) to a high speed compressor/turbine unit running at 16,500 RPM.

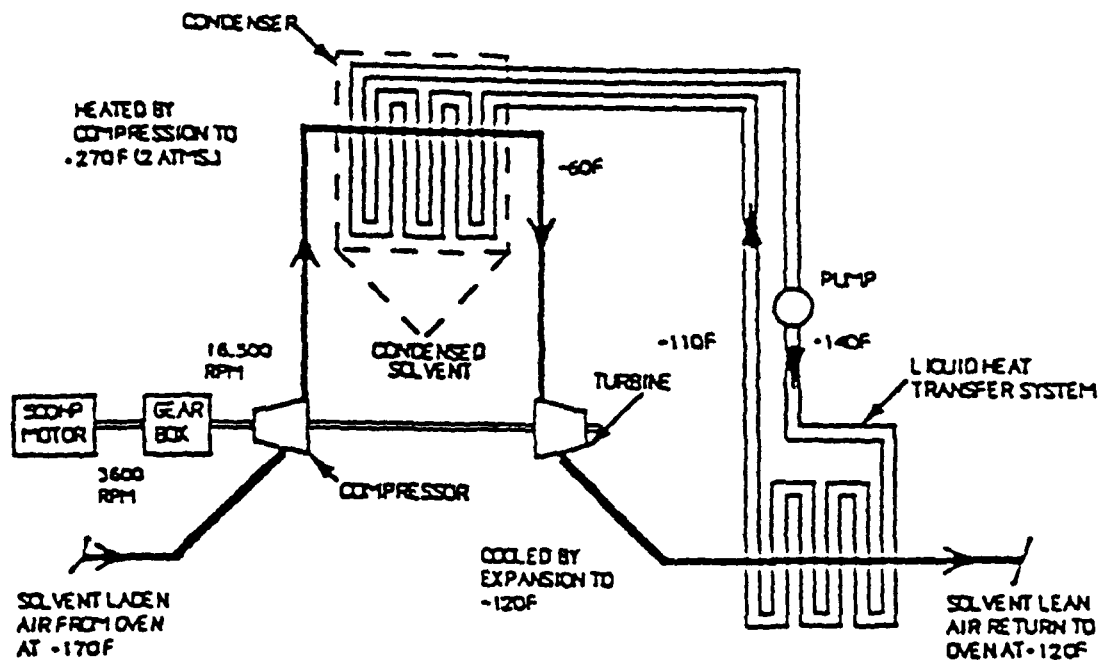


Figure 3 - Simplified 9000 SCFM 3M Hutchinson Brayton System

Learning from the experiences of the Hutchinson system, 3M worked with Nucon to design and install the second industrial Brayton cycle system at the 3M Weatherford, OK plant beginning in 1985. The Weatherford design differed from the Hutchinson design as follows:

- 1) Activated carbon beds are used to adsorb and concentrate solvent from the VOC stream.
- 2) The BCFP is used to regenerate the carbon bed with inert nitrogen gas.
- 3) A molecular sieve is used as an intermediate step between the adsorption and regeneration of the carbon bed to eliminate water (and thus ice formation) from the BCFP solvent laden nitrogen stream.
- 4) A free spindle compressor-expander is used in combination with a rotary blower to provide the compressor/expansion package. That is, the shaft power input to the BCFP system was decoupled from the compressor/expander package to eliminate

the high speed gear box used in the Hutchinson design. This free spindle compressor/expander was a modified design of the Garrett Industrial Products Division's largest diesel turbocharger.

Figure 4 shows the overall solvent recovery process in which the two carbon beds are cycled between step 1 and steps 2 to 4. That is, while one bed is adsorbing solvents at step 1, the other is being regenerated by step 2 (carbon dehydration), step 3 (carbon solvent desorption with the reverse Brayton cycle) and step 4 (molecular sieve regeneration).

The Weatherford system has been operating for over 1.5 years with over 99 percent up time. A more detailed description of the Weatherford process is presented in reference (4) by Kovach of Nucon.

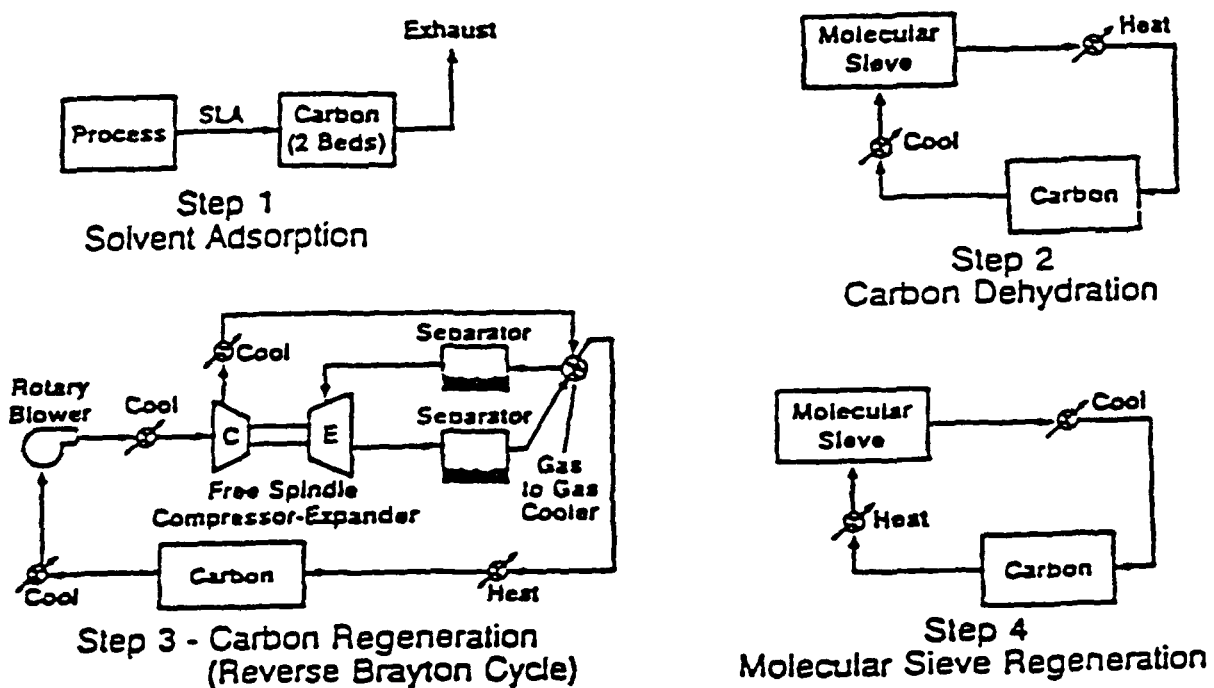


Figure 4 - 3M Weatherford Brayton/Concentrator System - Overall Process

## Advanced Brayton Design

In considering the recycle of solvents, equipment selection will be dictated by capital and operating cost. The solvent type, VOC stream flow size, VOC concentration level and the degree to which the VOC must be controlled (i.e. percent recovery) are all factors influencing cost.

To illustrate the economics of solvent recycling, the Greenville plant installation costs will be detailed for the proposed advanced Brayton design and other alternative approaches to controlling the VOC emissions from the coater at this plant. The VOC stream to be controlled at Greenville is an 8000 SCFM SLA stream with a concentration of approximately 2000 ppmv. The solvents used are heptane, xylene, toluene and isopropylalcohol (IPA).

Figure 5 shows the preliminary design of the advanced Brayton system. The Brayton regeneration system will provide a dry inert nitrogen stream for solvent stripping to one of the two adsorbent beds and then will remove over 99 percent of the solvents from the solvent laden nitrogen (SLN) once the SLN is returned from the adsorption bed. (The other adsorption bed is adsorbing solvents from the SLA stream coming from the coater.) This process was developed by Nucon under Phase I of the DOE project. The process is trade marked BRAYSORB™. Figure 6 shows the temperature versus pressure plot of this system. Note that the temperature of the adsorber is 320°F (160°C) and therefore no additional process heating is needed to regenerate the adsorbent beds. This means that electricity is only needed to drive the Brayton system eliminating the need for steam production or auxiliary heating systems.

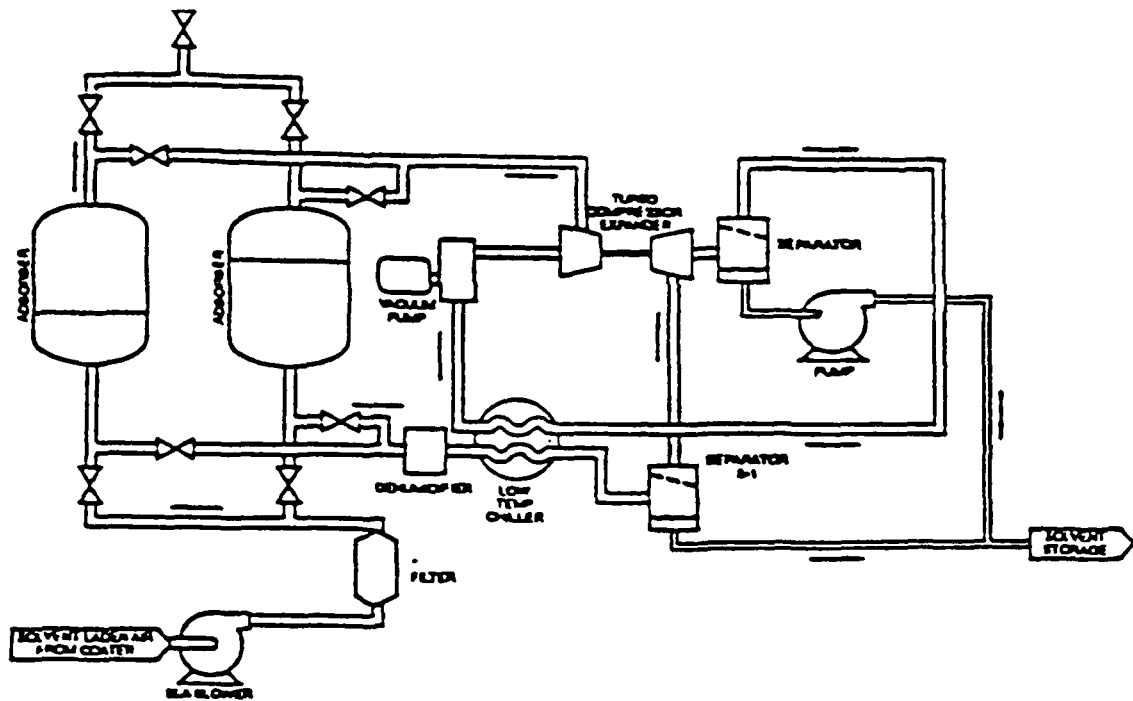


Figure 5 - Advanced Brayton/Adsorption System for 3M Greenville Plant  
(Figure represents Nucon BRAYSORB™ process)

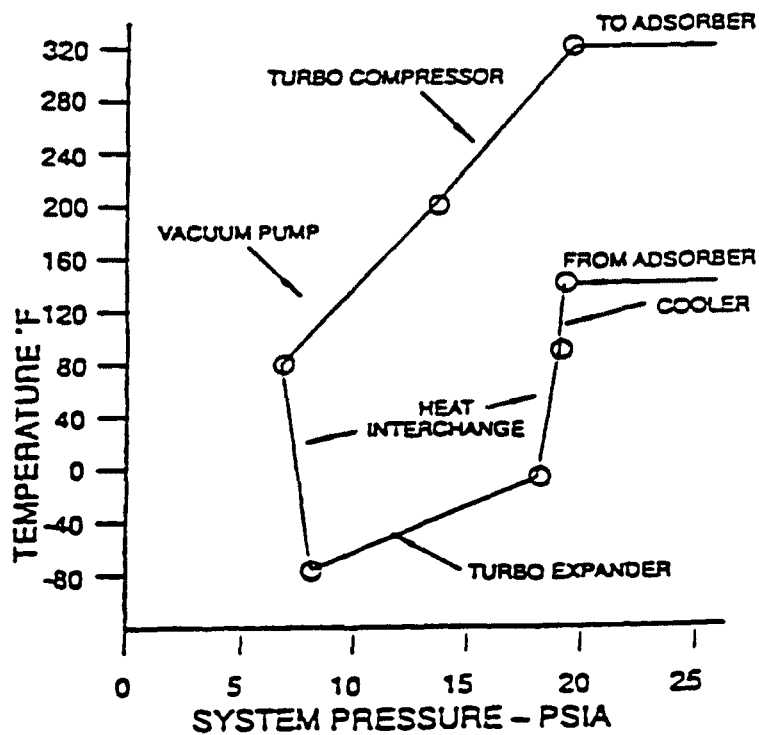


Figure 6 - Temperature versus Pressure Plot of BRAYSORB™ Process

Figure 7 shows a generic steam regeneration system analyzed for evaluation purposes to determine cost competitiveness of the Brayton system to other alternative designs. If the solvents are not miscible or slightly miscible, a decanting system will separate the majority of the solvents from the steam condensate satisfactorily. The contaminated condensate, however, will need to be treated by an air stripper.

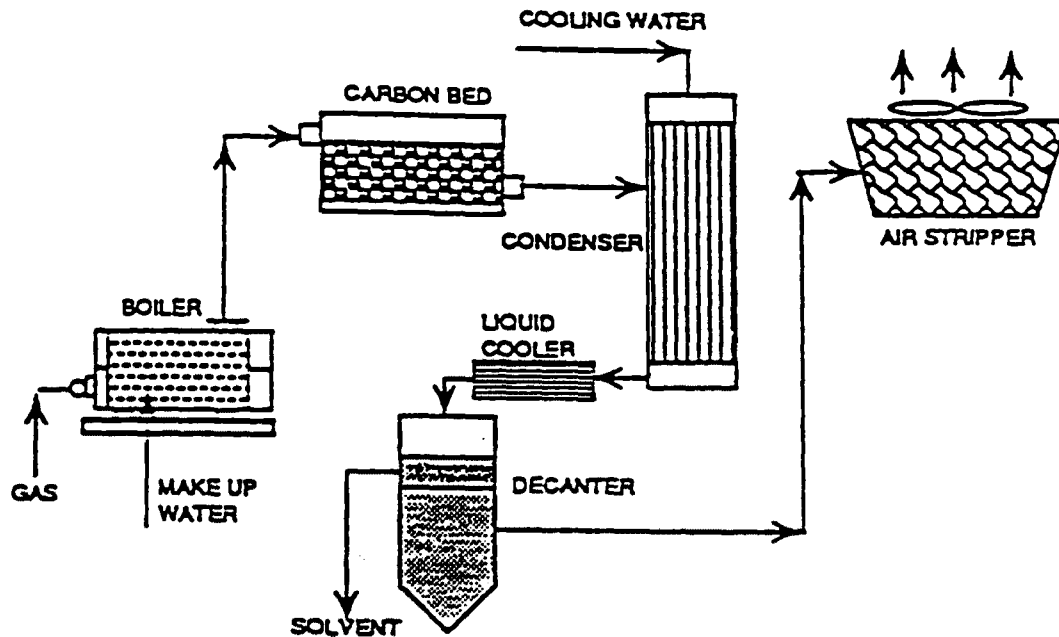


Figure 7 - Steam Regeneration System with Decanting Solvent/Water Separation

Figure 8 shows a schematic of a reverse Rankine system. This system has two cooling systems, one with a 30°F (-1°C) and one with a -80°F (-62°C) evaporator coil cooling temperature. The SLN stream is cooled to -75°F (-59°C) which is the same temperature as that achieved by the Brayton system. This allows for equal comparison of the Brayton and Rankine systems since approximately the same percent solvent recovery should be accomplished.

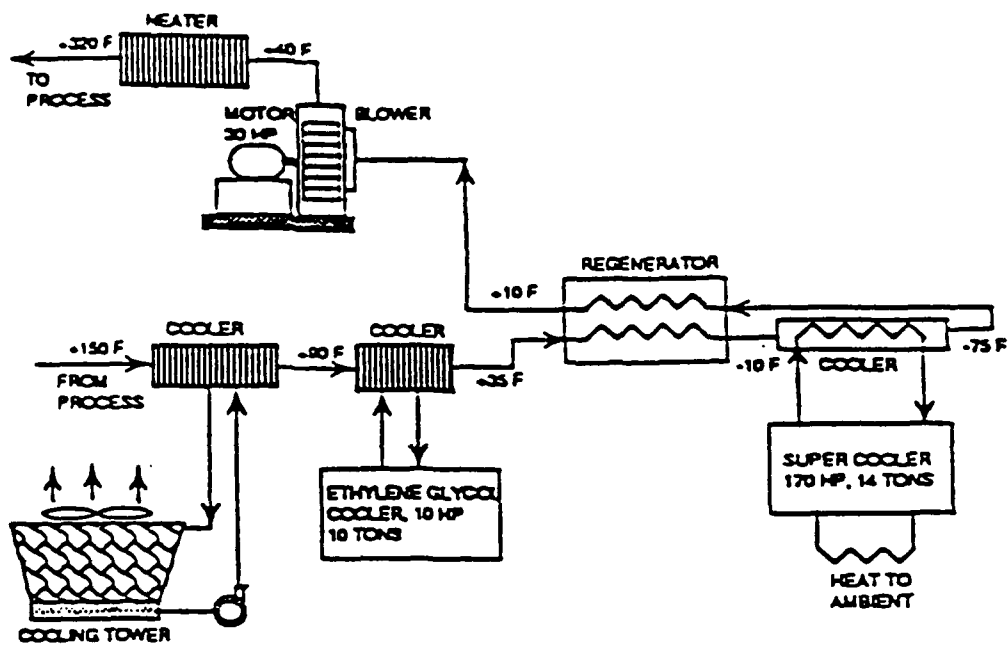


Figure 8 - Reverse Rankine Cooled/Inert Gas Regeneration System

Finally, an incineration system is shown in Figure 9. This system is a high efficiency unit since heat regeneration takes place. No heat recovery is attempted to provide heat to the plant's utilities needs. The solvents that are burned account for over 50 percent of the fuel heating value in the combustion process.

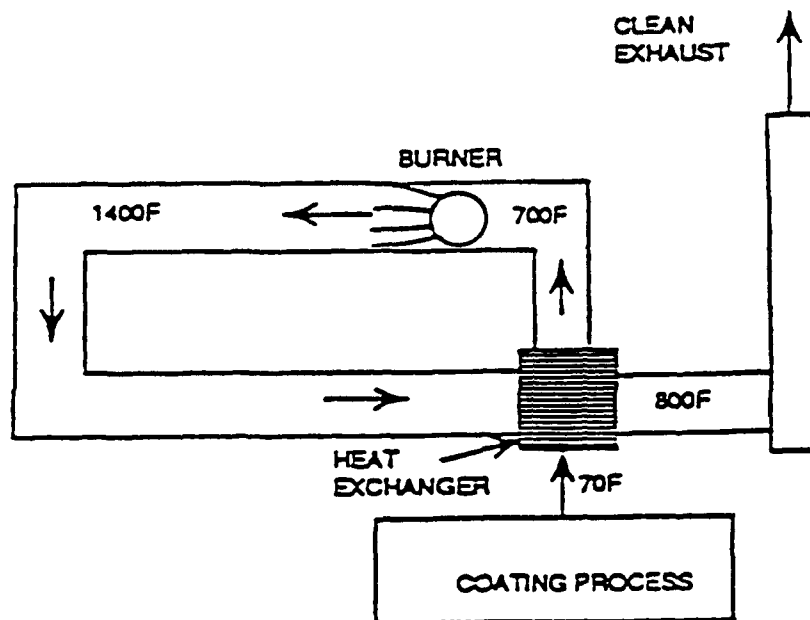


Figure 9 - Regenerative Incineration System

Tables 1 compares cost and performance of these four systems. Tables 2 to 4 give a cost breakdown of the three recovery options. Table 5 estimates installation costs of the VOC control options.

Table 1 - Cost and Performance Comparison of Four VOC Control Designs for the 3M Greenville, SC Plant

	Brayton	Steam	Rankine	Incineration
Equipment Cost	\$ 565,000 (see Table 2)	\$ 500,000 (See Table 3)	\$ 625,000 (See Table 4)	\$ 540,000
Installation Cost (See Table 5)	\$ 700,000	\$ 800,000	\$ 760,000	\$ 360,000
Total Capital Cost	\$1,265,000	\$1,300,000	\$1,385,000	\$ 900,000
Depreciation & Period	\$ 180,714 7 Years	\$ 185,714 7 Years	\$ 197,857 7 Years	\$ 128,571 7 Years
Energy Requirement & (Type)	139 KW (E)	40 KW (E) 1.33 MMBH (NG)	180 KW (E) 0.75 MMBH (NG)	3.00 MMBH (NG)
Energy Cost *	\$ 48,000	\$ 56,000	\$ 97,200	\$ 77,800
Inert Gas Cost * & (Amount)	\$ 3,000 (800 scf/day)	0	\$ 3,000 (800 scf/day)	0
Labor Cost*	\$ 33,280 16 hrs/wk	\$ 33,280 16 hrs/wk	\$ 33,280 16 hrs/wk	\$ 16,640 8 hrs/wk
Maintenance Cost* (% of Equip Cost)	\$ 113,000 (20%)	\$ 100,000 (20%)	\$ 137,000 (20%)	\$ 108,000 (20%)
Total O&M Cost	\$ 197,280	\$ 189,280	\$ 270,480	\$ 202,440
Solvent Recovery (lbs per hour) (lbs per year)	270 2.33 MM	265 2.28 MM	270 2.33 MM	0 0
Solvent Savings (\$'s per year)	\$ 279,600	\$ 274,000	\$279,600	
Annualized Cost (\$'s per year)	\$ 98,394	\$ 100,994	\$ 188,737	\$ 331,011
Simple Payback of Recovery over Incineration	1.57 Yrs	1.74 Yrs	3.4 Yrs	-
Simple Payback (solvent at 30 cents per lb)	2.5 Yrs	2.62 Yrs	3.23 Yrs	NA

Economic Factors

operation hours per year - 8640  
electricity rate - 4 cents/Kw-Hr  
natural gas cost - \$3.00/MM BTU  
boiler efficiency - 75%  
labor rate - \$40 per Hr  
solvent recycle value - \$.12/lb

\* Costs are annual      E = Electricity    NG = Natural Gas    MMBH = Million BTU/Hr

**Table 2 - Brayton Regenerated System Cost Breakdown**

Free-spindle Compressor/Expander	\$ 40,000
Drive Compressor	\$ 40,000
Regenerative Heat Exchanger	\$ 40,000
Precooler (water cooling)	\$ 10,000
Piping & Valves	\$ 50,000
Separators & Receivers	\$ 30,000
Instrumentation & Controls	\$ 90,000
Structural Skidding, Mounting, Misc.	\$ 40,000
Adsorber Structure (Carbon Steel)	\$ 60,000
Activated Carbon (20,000 lbs @ \$2/lb)	<u>\$ 40,000</u>
Total Equipment Cost	\$440,000
Engineering	\$ 75,000
Profit	<u>\$ 50,000</u>
Total Equipment Cost	\$565,000

**Table 3 - Steam Regenerated System Cost Breakdown**

Boiler (1000 lb/hr Steam)	\$ 20,000
Decanter & Condenser	\$ 50,000
Piping & Valves	\$ 50,000
Instrumentation & Controls	\$ 50,000
Structural Skidding, Mounting, Misc.	\$ 40,000
Adsorber Structure (304 Stainless)	\$ 80,000
Activated Carbon (20,000 lbs @ \$2/lb)	\$ 40,000
Cooling Tower	\$ 30,000
Water Treatment System	<u>\$ 50,000*</u>
Total Equipment Cost	\$ 410,000
Engineering	\$ 50,000
Profit	<u>\$ 40,000</u>
Total Equipment Cost	\$ 500,000

\* Site dependent - Cost may be as high as \$500,000

Table 4 - Rankine Regenerated System Cost Breakdown

Precooler (water cooling)	\$ 10,000
Precooling Refrigeration Unit	\$ 20,000
Regenerative Heat Exchanger	\$ 20,000
Super-cooler Refrigeration Unit	\$ 150,000
Regenerator Blower	\$ 10,000
Heating Unit	\$ 10,000
Piping & Valves	\$ 50,000
Separators & Receivers	\$ 30,000
Instrumentation & Controls	\$ 90,000
Adsorber Structure (Carbon Steel)	\$ 60,000
Activated Carbon (20,000 lbs @ \$2/lb)	<u>\$ 40,000</u>
Total Equipment Cost	\$ 490,000
Engineering	\$ 75,000
Profit	<u>\$ 60,000</u>
Total Equipment Cost	\$ 625,000

Table 5 - Cost Breakdown of Installation of VOC Control

	<u>VOC Recovery</u>	<u>VOC Incineration</u>
Engineering	\$ 50,000	\$ 50,000
SLA Fan, Filter, Cooler, Ducting	\$ 100,000	\$ 100,000
Site Preparation *	\$ 250,000	\$ 120,000
Tank Farms	\$ 150,000	\$ 0
Equipment Installation	\$ 100,000	\$ 40,000
Process Instrumentation	<u>\$ 50,000</u>	<u>\$ 50,000</u>
Total Installation Cost	\$ 700,000	\$ 360,000

\* Add \$60,000 for a building enclosure on the Rankine system

\* Add \$100,000 for a cooling tower installation for a Steam system

A few conclusions can be made from the above tables:

- 1) All the solvent recovery technologies have lower annualized operating cost than incineration. Also, the incremental investment of all three recovery technologies over the cost of the incineration system yields a 1.5 to 3.5 years payback based on the aggregate savings of the recycled solvents and the difference in operating costs of the recovery options and incineration. In the future if the solvent price were, for instance, 30 cents per pound for this application then the payback on Brayton and steam regeneration system would be less than 3 years.

- 2) The Brayton system costs are estimated to be competitive with the well established recovery technologies. This cost estimate of the Brayton system is for the third generation design. Further cost reduction can be expected in the future. For this reason, 3M is pursuing this technology so that their choices on controlling VOCs may be broadened. Likewise, the DOE sees the Brayton technology as a vehicle to reduce energy consumption of VOC control technologies and, to proliferate solvent recycling with more cost effective recycling with both large and small solvent users and thereby reduce demand for energy intensive solvent production nationwide.

### Summary of the Progression of the Brayton Cycle Technology

The main accomplishments over the last 15 years on the Brayton cycle solvent recovery technology have been to reduce capital cost, reduce energy consumption and improve reliability of the equipment. Table 6 summarizes the performance of the two 3M Brayton systems already installed (Hutchinson and Weatherford) and the expected performance of the planned Greenville plant installation.

**Table 6 - Progression of Cost and Performance  
Improvements with the BCHP at 3M**

	<u>Hutchinson</u>	<u>Weatherford</u>	<u>Greenville</u>
SLA Stream Size (SCFM)	9000	9000	8000
Time period designed & Built	1979 - 1984	1985 - 1987	1988 - 1991
Solvent Type	MEK, Toluene, Cyclohexanone	MEK, Toluene, Cyclohexanone	Heptane, Xylene Toluene, IPA
VOC Conc. (PPMV)	4000	2000	2000
Power Required (HP)	550	450	180
Equipment Cost	\$1,500,000 <sup>(1)</sup>	\$1,000,000 <sup>(1)</sup>	\$ 565,000 (From Table 2)

<sup>(1)</sup> Estimated equipment costs in 1990 dollars to replicate the installed equipment. This does not include installation cost.

### Summary

In summary, substantial improvements have been made on the Brayton cycle technology, especially in the last two years. Stricter environmental regulations for VOCs creates a demand in industry for VOC control equipment at reduced cost. Higher solvent prices will also further enhance the economics of solvent recycling over incineration. The DOE and 3M therefore remain committed to this technology.

### Conclusions

A three phase cooperative effort between the U.S. DOE, 3M, and Nucon International is about to enter the Phase II effort to design and fabricate a Brayton Cycle Heat Pump system to control an 8000 SCFM VOC air stream. Estimates from a preliminary design shows that

the equipment cost and energy consumption have both been more than halved from the previous generation design at 3M. This new and advanced system is expected to be operational sometime in 1992. This design will form the basis for other 3M facilities and other companies with similar VOC control needs to follow through with implementation of other cost competitive Brayton Cycle Heat Pump installations.

### References

- (1) Heat and Liquid Recovery Using Open Cycle Heat Pump System,  
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- (2) Vapor Recovery Method and Apparatus,  
Leslie R. Flink, Bryce J. Fox, Mary K. Witzel, 3M  
U.S. Patent #4,480,393, Dated November 6, 1984
- (3) Heat and Liquid Recovery Using Open Cycle Heat Pump System  
Bryce J. Fox, 3M; U.S. Patent #4,539,816, Dated September 10, 1985
- (4) Full Size Industrial Application of the Brayton Cycle Heat Pump in Adsorption Concentrator, J. L. Kovach, 1989 ASME Winter Annual Meeting, AES-Volume 8 (Advances in Industrial Heat Pumps Technology - 1989). December, 1989