



ENGINEERING CONTROL
RESEARCH RECOMMENDATIONS

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ABSTRACT

By analysis of use/exposure data compiled for toxic substances regulated by 29 CFR 1910.1000, ten industries and twelve common industrial operations were selected for study. Each industry/operation was investigated to determine whether effective engineering controls exist to prevent excessive employee exposures to toxic agents utilized in the equipment and processes involved. Recommendations for engineering control research were developed which addressed identified needs. These recommendations were then prioritized according to their perceived capability to result in beneficial technology.

The industries studied included pharmaceutical manufacturing, plastic and foam manufacturing, paint and coatings manufacturing and application, rubber production, pesticide manufacturing and application, adhesive manufacturing and application, dye and ink manufacturing, soap and detergent manufacturing, perfume manufacturing, and printing. The common industrial operations were abrasive machining; chemical processes; cleaning and maintenance; drying and curing oven use; grinding, crushing, and screening; laboratory operations; non-spray application of volatile substances; open-surface tank use; spray-finishing; coating and dyeing; and welding.

1. INTRODUCTION

1.1 BACKGROUND

The National Institute for Occupational Safety and Health (NIOSH) and The Occupational Safety and Health Administration (OSHA) have initiated a joint program, the Standards Completion Program (SCP), with the objective of providing specific standards for each of the over 400 toxic substances identified by 29 CFR 1910.1000. As part of this program, Arthur D. Little, Inc., (ADL) has been developing engineering, personal protective, and administrative control standards under Contract No. CDC-99-74-44 and has developed recommended industrial ventilation guidelines for selected industries or operations under Contract No. CDC-99-74-33. The recommended ventilation guidelines will be published in report form to demonstrate the feasibility of engineering control use in the specific process and operation categories investigated.

It is imperative for NIOSH to systematically and selectively identify those problem areas where research can have the greatest impact on the health and safety of the American working population. Consequently, NIOSH identified a need for prioritized research recommendations pertaining to the provision of adequate engineering controls for prevention of worker exposure to toxic substances utilized in industrial processes and operations.

ADL conducted a program to identify industrial processes which have significant potential for resulting in excessive worker exposures and to determine whether engineering controls of proven adequacy exist for them. Additionally, it developed and prioritized recommendations for engineering control design and performance research where needs for such research were identified.

1.2 PROGRAM OBJECTIVES

It was the purpose of this study to assist NIOSH by taking advantage of the data accumulated by ADL in the performance of aforementioned contracts. Specifically, the objectives of the program were:

1. To identify industries or specific operation and process categories in industry which have considerable potential for exposing large numbers of workers to toxic substances;
2. To examine and evaluate these problem areas with the objective of determining the availability and/or adequacy of engineering controls;
3. To justify, recommend, and specify the research activities necessary to provide the technology for effective engineering controls, where needs are identified; and
4. To prioritize the recommendations and/or the problems they represent in a reasonable and logical manner.

2. METHODOLOGY

2.1 INTRODUCTION

To most effectively apply the resources allocated to this study, it was necessary to develop an approach which utilized the available data to best advantage. In the following, the sources and compilations of data which were available are described, and we present the rationale for the work approach utilized in this program.

2.2 LITERATURE SOURCES OF INFORMATION

The primary data base for this study consisted of a large compilation of literature collected during our previous work for NIOSH. To this data base, other information was to be added as needed on a case-by-case basis. The data base consisted of a library and a system of chemical-specific, industry, and engineering control data files.

The carefully selected library served as the core of the data base. Included were well-known texts on toxicology, industrial hygiene, and ventilation, and texts which specifically described the operations and processes conducted in various industries.

In the initial stages of the program to develop engineering, personal protective and administrative control standards for the individual chemicals regulated by 29 CFR 1910.1000, an intensive literature search was conducted of reports and periodicals to compile data on the uses of individual chemicals, and their physical, chemical, and toxicological properties. These data were available in a set of "chemical-specific" files, one for each chemical of concern. Each file also contained a computer printout of abstracts of papers, etc. which the NIOSH Technical Information Service had provided for each chemical of interest.

This initial, intensive literature search also generated a data base which was termed as an "industry file." Here were collected, by individual industry, various papers, booklets, reports, etc. which described the processes and operations conducted therein and the problems with exposure to hazardous materials. Since these files often contained data of interest for specific chemicals, they were cross-referenced with the "chemical-specific" files.

Prior to and during the study to develop recommended industrial ventilation guidelines, yet another literature search was conducted. This search was directed at gathering available information on the application of general and local exhaust ventilation for controlling exposures, and resulted in "engineering control" files for various industries and operation categories.

2.3 USE/EXPOSURE DOCUMENTS

To provide information essential to defining where toxic substances are primarily employed in industry and what their impact is upon overall worker health, ADL prepared for NIOSH what is termed a "use/exposure" document for each of the chemicals treated to date in the SCP. Each of these documents identifies for its chemical of concern those industrial operations or processes which cause significant and common employee exposures to occur and presents its findings in a list which is rank ordered by a methodology which was developed. The operations appear in order of their relative hazard potential for a specific chemical and any given ranking is not directly comparable to the ranking of an operation, similar or otherwise, conducted with another chemical.

Table 1 shows a typical example of one such document. The left column lists the individual operations or processes identified from literature and other sources of information in an order indicated by the aforementioned methodology. The center column notes the primary routes of exposure by which the substance acts, and the final column reports which personal protective and engineering controls have been cited as being applicable for preventing harmful exposures. At the point in time when this program was initiated, 210 of the approximately 400 such documents to be prepared had been completed.

2.4 SELECTION OF OPERATIONS CATEGORIES FOR STUDY

The primary source of data specified for use in selecting operation categories for study was the set of use/exposure documents prepared for the chemicals of interest to the SCP. As previously noted, these documents listed and ranked the most significant uses of each chemical in a "relative" manner, i.e., though the ranking procedure used resulted in use/exposures "relatively" ranked within each document, the ranking was not "absolute" in the sense that the significance of the uses and exposures of one chemical could be compared to those of another.

To assemble these data into a form which would allow overall analysis, the use/exposure documents for the first 210 chemicals addressed in the SCP were employed to develop a set of matrices indicating the name of each compound, and the significant operations, processes, or industries it is utilized in. The set of these matrices, given in order of the "sets" of chemicals in which the SCP was divided, is presented in Appendix A. To be noted is that the operation categories described across the top of these matrices are somewhat generalized to accommodate the multitudinous specific uses listed in the actual documents. Indeed, many of the checked blocks represent more than one specific use/exposure.

The determination of which of these categories were most significant overall required that they be somehow ranked by order of their potential to result in exposures. Attempts to do so, utilizing various

TABLE 1

USE/EXPOSURE AND CONTROL DOCUMENT		
ISOBUTYL ACETATE		
Use/Exposure	Principal Route of Entry	Currently Used Control Methods
1. Inhalation of vapor during spray application of varnishes and nitrocellulose lacquers as protective and finish coatings for wood (especially in the furniture industry), plastic, metal, leather and other surfaces	A	Local exhaust ventilation; personal protective equipment (respiratory protective devices)
2. Inhalation of vapor during application of varnishes and nitrocellulose lacquers as protective and finish coatings for wood, paper (printing ink vehicle), metal leather, and other surfaces by dipping, roller coating, tumbling, knifing or brushing	A	Local exhaust ventilation; general dilution ventilation
3. Inhalation of vapor during oven baking of phenolic and epoxy coatings	A	General dilution ventilation
4. Inhalation of vapor during air or oven drying of varnishes and lacquers	A	General dilution ventilation
5. Inhalation of vapor during application of nitrocellulose, cellulose acetate, cellulose acetate butyrate and cyclized rubber adhesives by machine spraying, dipping, roller coating, tumbling, knifing, or brushing. Most common industrial applications are in shoe manufacturing, book binding, packaging, leather processing, photographic film manufacturing, and paper processing	A	Local exhaust ventilation; general dilution ventilation
6. Inhalation of vapor and skin contact with liquid during manual application of nitrocellulose (household cements), cellulose acetate, cellulose acetate butyrate and cyclized rubber adhesives	A,B	Local exhaust ventilation; general dilution ventilation; personal protective equipment (gloves and aprons)

- | | | | |
|----|---|-----|---|
| 7. | Inhalation of vapor and skin contact with liquid during cleaning and maintenance of acetate processing equipment such as kettles distillation columns and storage vessels | A,B | Personal protective equipment (respiratory protective devices, gloves, aprons, barrier creams, eye goggles) |
| 8. | Inhalation of vapor during the manufacture of some perfumes, cosmetics, and flavoring agents | A | General dilution ventilation |
| 9. | Inhalation of vapor during spray application of vinyl based primers, maintenance paints and other industrial coatings | A | Local exhaust ventilation; personal protective equipment (respiratory protective devices) |

- A -- Inhalation
- B -- Skin contact resulting in localized irritation
- C -- Ingestion
- D -- Skin contact resulting in absorption and subsequent systemic poisoning

procedures, resulted in the conclusion that the only practical basis for doing so was by simply determining the number of chemicals utilized in any individual category and by listing the categories according to this ranking. Table 2 presents the operation categories in the order determined by this procedure. While it is realized that the mere fact that more toxic substances are used in one process than another does not prove that it is more hazardous than another, no other procedure which a priori indicated the degree of hazards involved could be developed from these data. Furthermore, there did appear to be considerable merit in an approach which makes no a priori assumptions that a particular type of operation can be effectively controlled and which results in the investigation of processes and operations in industry which involve the use of the largest numbers of toxic substances.

Examination of Table 2 indicated that some categories listed are inherently included within others, and that some were breakdowns of a more general category. For example, it could be seen that the categories of fuel production, lubricant manufacture, heat transfer fluid use, petroleum refining, and refining and dewaxing of mineral oil could be considered as being inherently included in closed-system "chemical processes". Additionally, such categories as "textile coating processes" and "textile dyeing" could be envisioned as the single category of "textile coating and dyeing processes", while "ink manufacturing" and "dye manufacturing" could be reasonably combined into "ink and dye manufacturing" because of perceived similarities in processes utilized and/or hazards involved. Before proceeding further, therefore, the list in Table 2 was condensed, using the reasoning exemplified, into the list presented in Table 3. While this table was very similar to Table 2, its differences served to better organize the operations into more identifiable categories and to eliminate redundancy.

It was then observed that Table 3 contained two types of categories; those which represent entire industries, and those which represent some set of similar equipment or activities which may be utilized or conducted in a number of industries. Pharmaceutical, plastic and foam, and paint and coating manufacturing are examples of the former type while chemical processes, cleaning and maintenance, and open-surface tank use are examples of the latter. Also observed was that some significant common operation categories were missing from Table 3; material handling and laboratory operations being prime examples.

With the realization that any investigation of engineering control use in a specific industry would involve consideration of common operations, it was perceived to be desirable to somehow delineate these common operations. This would allow their separate and complete study and reduce the possibility of redundant efforts. Furthermore, since an objective of the program was to develop research recommendations having the greatest potential benefit to the working population, it was decided that study of these common operations must be given priority over study of any industry-specific problem areas. To accomplish these objectives, a "two-tiered" study approach, as described in the following paragraphs, was instituted.

TABLE 2
OPERATION CATEGORIES IDENTIFIED FROM
USE/EXPOSURE DOCUMENTS

<u>Rank</u>	<u>Operation Category</u>	<u># of Chemicals</u>
1.	Chemical processes	170
2.	Cleaning and maintenance operations	103
3.	Pharmaceutical manufacturing	74
4.	Extractant or solvent use	73
5.	Plastic and foam manufacturing	73
6.	Paint manufacturing	71
7.	Rubber production	53
8.	Pesticide manufacturing	53
9.	Manufacture and application of adhesives	50
10.	Dye manufacturing	49
11.	Non-spray application of paints, etc.	47
12.	Spray-finishing	45
13.	Textile coating processes	43
14.	Pesticide application	37
15.	Cleaning and degreasing	37
16.	Textile dyeing	34
17.	Photographic film and chemical manufacturing	34
18.	Fuel production	32
19.	Ink manufacturing	28
20.	Detergent manufacturing	28
21.	Perfume manufacturing	26
22.	Ink application	21
23.	Electric equipment manufacturing	20
24.	Leather tanning and treatment	20
25.	Lubricant manufacture and use	19
26.	Synthetic fiber manufacturing	19
27.	Dry cleaning operations	17
28.	Manufacture of polishing compounds	16
29.	Heat transfer fluid use	15
30.	Use of paint or varnish removers	15

TABLE 2 (Cont'd)

<u>Rank</u>	<u>Operation Category</u>	<u># of Chemicals</u>
31.	Aerosol manufacturing and use	15
32.	Mining operations	15
33.	Manufacture and use of pyrotechnics and explosives	13
34.	Refrigerant use	13
35.	Petroleum refining	12
36.	Machining, grinding, buffing, and polishing	11
37.	Food additive use	10
38.	Manufacture and use of corrosion inhibitors	10
39.	Ore refining and metal processing	10
40.	Ceramics and glass production	9
41.	Welding	8
42.	Drying of paints, varnishes, etc.	8
43.	Manufacture and use of fire extinguishers	8
44.	Refining and dewaxing of mineral oil	7
45.	Foundry processes	7
46.	Cosmetic manufacturing	6
47.	Anesthetic use	5
48.	Artificial leather manufacturing	4
49.	Water purification	4
50.	Safety glass manufacturing	3
51.	Food processing	3
52.	Smokeless powder manufacturing	3
53.	Pulping of wood	3
54.	Paper impregnation	2
55.	Straw hat manufacturing	2
56.	Synthetic pine oil manufacturing	1

TABLE 3

CANDIDATE INDUSTRIES AND OPERATIONS FOR INITIAL STUDY

- | | |
|--|---|
| 1. Chemical processes | 21. Manufacture of polishing compounds |
| 2. Cleaning and maintenance | 22. Aerosol manufacturing and use |
| 3. Pharmaceutical manufacturing | 23. Mining operations |
| 4. Plastic and foam manufacturing | 24. Pyrotechnics and explosives manufacturing |
| 5. Paint and coatings manufacturing | 25. Abrasive machining |
| 6. Rubber production | 26. Food processing |
| 7. Pesticide manufacturing and application | 27. Manufacture and use of corrosion inhibitors |
| 8. Adhesive manufacturing and application | 28. Ore refining and metal processing |
| 9. Dye and ink manufacturing | 29. Ceramics and glass production |
| 10. Non-spray application of volatile substances | 30. Welding |
| 11. Spray-finishing | 31. Dryer and oven use |
| 12. Textile coating and dyeing processes | 32. Manufacture and use of fire extinguishers |
| 13. Open-surface Tank Use | 33. Foundry processes |
| 14. Soap and Detergent Manufacturing | 34. Cosmetic manufacturing |
| 15. Perfume manufacturing | 35. Anesthetic use |
| 16. Printing | 36. Artificial leather manufacturing |
| 17. Electric equipment manufacturing | 37. Water purification |
| 18. Leather tanning and treatment | 38. Pulping of wood |
| 19. Synthetic fiber manufacturing | 39. Paper impregnation |
| 20. Dry cleaning | 40. Straw hat manufacturing |
| | 41. Synthetic pine oil manufacturing |

In Section 3 of this report, the first 10 industries identified in Table 3 are individually studied and reported upon. These "industry evaluations" attempt to describe the activities conducted in each industry, determine how, when, and where exposures to toxic substances may occur, and assess the availability and adequacy of engineering controls. For this latter task, they concentrate upon those activities which can be considered somewhat unique to the industry. Those operations common to many industries are simply noted as being such and listed for further consideration.

Section 4 of the report is concerned with an evaluation of the availability and adequacy of engineering controls for the common operation categories either identified in Section 3 or appearing in Table 3. Thus, this "two-tiered" approach results in detailed study of not only a set of industries in which large numbers of toxic substances are utilized, but also in the study of common operations conducted throughout industry from which exposures are likely to occur.

2.5 PRIORITIZATION OF RECOMMENDATIONS

Section 5 of the report summarizes the research recommendations developed in Sections 3 and 4 and prioritizes them according to their perceived capability to result in beneficial technology. The approach taken in this endeavor is presented and discussed fully in that section.

2.6 LIMITATIONS OF THE APPROACH

There are a number of limiting factors to the approach utilized vis-a-vis its appropriateness in fulfilling the objectives of this study. These are discussed in the following:

The first area of concern involves the data from which Tables 2 and 3 were derived. As previously reported, only 210 of the 400 use/exposure documents to be prepared had been completed at the point in time their use was necessary for this study. This suggests the possibility that a similar analysis procedure conducted at the completion of the SCP program might lead to listings of industries and operations of somewhat different ordering. Since we only studied those selected from the top portion of Table 3, however, we can be confident that they would be present at or near the top portion of any future listing prepared.

The number of industries investigated in Section 3 represents a second limitation. It was originally intended that all industries on the list would receive attention. However, it was determined that the amount of effort required per industry evaluation was beyond the resources allocated to the study. While considerable information existed which described the activities of any given industry, that which described the exposure problems and the availability and adequacy

of engineering controls were not so readily available. Thus, data collection efforts would have been necessary beyond compilation of the information already inhouse and/or readily available.

Restriction of the number of industries selected from Table 3 to a total of 10 indicates that any unique problem areas in the industries not studied could not be identified. The "two-tiered" approach of study, however, leads us to the conclusion that problems common to many industries were sufficiently addressed. While it cannot be guaranteed that all such common problem areas were identified, it can be said with confidence that very few, if any, others exist which might be of a significance to warrant research activities.

Finally, some comment is warranted concerning the validity of the numerous conclusions drawn throughout the report. Wherever possible, such conclusions can be seen to logically evolve from the data presented. However, in some cases, it was necessary to base conclusions upon our own judgement and a limited amount of information available in the public domain. Though we have considerable confidence in the validity of these judgements, one can never ensure that such a conclusion is entirely a correct one.

2.7 OTHER TOPICS

In Section 6 of this report, the authors present a discussion of some problem areas and topics not previously noted in preceding sections. Included are a number of ideas and concepts which evolved during performance of this work and which do not properly belong in preceding sections.

3. INDUSTRY EVALUATIONS

3.1 INTRODUCTION

For each of the first 10 industries listed in Table 3, this section contains an individual evaluation. These evaluations describe the operations and processes conducted in the industry, indicate which production stages or areas have been noted in the literature as presenting exposure hazards to workers, and discuss the availability and adequacy of engineering controls where needs for them are evident.

At the end of the evaluations for the first six industries addressed, a summary list of operations common to many industries is presented. The operations so listed, together with others found in Table 3, constitute the total of those investigated in Section 4 of this report. Such lists are not presented in the remaining four evaluations because of the redundancy of doing so. No new common operations were identified in these latter evaluations.

3.2 PHARMACEUTICAL MANUFACTURING

Introduction

The pharmaceutical industry has grown from predominantly individual endeavors into an industry characterized by the drugstore pharmacist and the complex organizations of modern corporations. Advancements in life sciences have resulted in the production of numerous varieties of medicines from chemical, animal, and vegetable sources.

According to Kirk-Othmer, ⁽¹⁾ pharmaceuticals are designed to perform one or more of a variety of functions -- (1) destroy disease producing organisms by interference with their cell processes, (2) produce a physiological effect by interference with the body's cell chemistry, (3) stimulate the body to produce protective substances, (4) replenish or supplement the body's natural supply of a substance and/or (5) produce some sort of functional physical effect.

When these substances are properly administered, they can provide benefits to victims of disease or trauma. Alternatively, where workers are excessively and unintentionally exposed to them, they can result in undesirable health effects. In the following, we describe the operations involved in the production of pharmaceuticals and discuss the availability and adequacy of engineering controls where needs for them can be identified. The major subject areas of concern are process development, manufacturing, and packaging.

Process Development

Process (and product) development involves the typical steps of development and testing of products in the laboratory, design and evaluation of production processes in small-scale pilot plant operations, and

the subsequent scale-up, design, and start-up of a full-scale plant. The processes and operations involved are by no means unique to this industry. Laboratory operations are usually typical of those conducted in chemical and biology labs. The operations conducted in the pilot plant phase of development and in the start-up of full-scale operations are characteristic of the chemical industry and the processes conducted therein. Included are evaporation, distillation, absorption, esterification, nitration, hydrogenation, and others.

Manufacturing

It is in the manufacturing of pharmaceuticals that one finds those operations or types of equipment which are primarily unique to the industry. In this characterization again cannot be included those operations or processes utilized to synthesize many basic ingredients, processes which must be considered as common to many industries and usually typical chemical unit operations.

Like so many other industries, the passing of time and the identification and appreciation of hazards to workers arising from physical and toxic agents have resulted in reductions, and even eliminations, of such hazards in the pharmaceutical industry. Indeed, one might consider that the present, somewhat dual regulation of the industry by the Food and Drug Administration and OSHA has accelerated the "desire" to control operations to a significant degree. This is not meant to imply, however, that protection of employees is always provided by engineering controls.

In 1947, Watrous⁽²⁾ described the health hazards of the pharmaceutical industry. He noted, "In recent years the pharmaceutical industry has come to occupy a unique position in regard to problems of industrial hygiene and toxicology; practically no other single commercial enterprise presents such a wide variety of potentially toxic exposures or such a rapidly-changing advent of new chemical substances." His paper continues by noting the hazards of many of the substances used at that time and repeatedly notes the need for sufficient knowledge of the hazards of toxic substances, proper instructions and warnings to those handling them, and proper control measures.

Bresler⁽³⁾, in a 1949 paper concerning nitroglycerin reactions among pharmaceutical workers, reported "the reaction from exposure to nitroglycerin represents an unpleasant and undesirable complication, causing the worker considerable discomfort and illness, and resulting in a production problem of some magnitude. The pharmaceutical industry has been faced with this problem for many years. Many control procedures have been instituted, none of which have proved entirely satisfactory." After describing the toxic effects of the substance and its method of manufacture, he then discusses methods of control. Of interest are his statements "Dust and vapors should be removed at their source by suitable ventilation measures. This should include a hood for the powder mixer. The tablet machine and the drying units should be enclosed and exhausted."

Speaking of his experiences "decades ago," Chilson⁽⁴⁾ reflects "in those days dust collection was inadequate, if not totally missing in most plants. Very dusty products were isolated within partitions. Cleaning up meant hosing down once a week. And ... conditions were truly appalling ..." In another article⁽⁵⁾, he states "all factories were, by current standards, dirty. Dust collection was virtually unknown, even when the products being made were hazardous. When such products were exceptionally dirty, irritating, or hazardous, the areas where they were made were enclosed within partitions. These areas usually had windows equipped with exhaust fans so that some of the dust could be spread all over the neighborhood. Men working in these areas were provided with dust masks, and, in the fine chemical industry at least, when poisonous chemicals were dumped into hoppers, the hoppers were designed to provide a downdraft. But such hoppers were used only when there was a danger that the dust might get through the masks and kill the operators."

The above describe typical conditions in the industry "decades ago" and represent one extreme of the conditions under which employees worked. Since then, of course, conditions have improved to the extent that the literature contains references to manufacturing systems which approach the opposite extreme. A description⁽⁶⁾ of a process for manufacturing aspirin tablets in 1967 fully illustrates this point.

In comparison to other substances manufactured in the pharmaceutical industry, aspirin must be ranked with those being the least hazardous. Nevertheless, at least one manufacturer has been capable of designing a system which virtually eliminates exposures. Indeed, once ingredients are manually fed to hoppers at the very beginning of the process, no other manual contact with the product is necessary. By use of tubular conveyors, the ingredients are fed at controlled rates to blenders, sifters, millers, compactors, granulators, and finally, to tableting presses -- all, or most, of which are totally enclosed and/or controlled by other means to reduce contaminant releases. The author reports that "strict sanitary requirements are met by the totally enclosed design of the conveyors and that no storage area is required as all material is either in the pipes, being conveyed, or in the systems compact storage hoppers."

The description of this system suggests it would be a simple matter to design all product lines in this industry in a similar, totally enclosed manner and thereby virtually eliminate toxic chemical exposures. Unfortunately, for this particular industry, this generally is neither a feasible or practical concept because a high volume, continuously-in-demand product such as aspirin is more an exception than a rule. If one could consider there is a "rule" of any kind, he would have to accept the concept that production equipment in the pharmaceutical industry is designed to be flexible and usable in various combinations to allow "changeovers" from one product line to another and the rapid development of methods to produce new products with existing equipment.

The 1971 design of Gerhart et al.⁽⁷⁾ for a potent drug production area can be considered to represent more realistically the layout of manufacturing areas in this industry. Essentially, the authors illustrate a layout consisting of a number of rooms, one for each of the major operations conducted; weighing, blending, drying and grinding, tablet compressing, and packaging. Batches of materials are manually handled at almost every step of the operation and manually transferred to the next area in line.

Where products other than tablets are manufactured, other types of operations may also be conducted. In the following, we therefore generally describe the important and currently utilized equipment and operations conducted in this industry for the three major forms of products -- tablets, capsules, and liquids.

Tablet Manufacturing^(1,8)

Generally speaking, there are three types of tablets--compressed, coated, and effervescent. The machinery utilized to produce the tablets from granulations are compressing machines of the single punch or rotary multiple-punch variety. These machines are peculiar to the pharmaceutical industry, and may produce thousands of tablets per minute.

A major problem at this stage of the operation is the dependance on a steady supply of free-flowing, uniform granulations. Each tablet is measured by volume instead of weight so that granulations must possess nearly identical physical properties, even though they may be prepared from numerous blended materials. Three methods are usually employed to ensure uniformity.

In the wet method, the active ingredients are milled and mixed, fillers and coloring materials are added, the mass is mixed again, and a binding agent is added. The resulting wet mass is screened, dried, blended with quantities of other ingredients, and then charged into a compressing machine. The dry method for granules is used where the nature of the ingredients does not allow exposure to heat or moisture without decomposition. A heavy-duty compressing machine is therefore used to compress powders into large "slugs" which are then broken up into the desired granulations, blended with other ingredients, and charged into a compressing machine. The direct method is employed when materials possess the physical properties desired without additional treatment.

Coated tablets are produced from compressed tablets with rounded edges (for even coating). Previous to coating, the tablets are screened to remove dust and broken tablets. Some compressing machines have screen chutes or vacuum dust removing devices for these purposes. Equipment used in actually coating the tablets consists of metal rotating pans, canvas-lined polishing pans, or jacketed kettles (for syrups).

Effervescent tablets are commonly made by the addition of an alkali bicarbonate with citric or tartaric acid to the formulation. The method followed is to warm the preparation in a rotating pan, rapidly dry under a vacuum and compress in a room with low humidity. Special precautions are necessary against moisture so that decomposition does not occur.

Capsule Manufacturing⁽¹⁾

Capsules are of two types, a hard type, made of gelatin and water and used to contain powder type medications, and a soft type, of gelatin containing glycerol, usually used for containing oily medications. Hard capsules are made leakproof by a very close fit and the processes for making them are usually fully automatic. The capsule body is formed, filled with powder from a hopper, united with its "mate" and blown dust free. Soft capsules are produced by a special rotating die process. This process makes and fills capsules simultaneously, and the capsule is made leak-proof by pressure sealing.

Liquid Processing⁽¹⁾

Liquids produced are of three types - aqueous, hydroalcoholic or oily. The formulation of any one of these types generally involves mixing, filtration, emulsification and/or homogenization.

Mixing of ingredients is accomplished in chemically resistant tanks of various types. Some may be jacketed to allow heating, cooling, or sterilization. Some are designed to withstand pressures to 50 psi and/or a moderate vacuum. Storage tanks, sometimes fitted with agitators, are used to store batches of product until needed. The former of these may be exposed at the top for easy access.

Once a medication has been formulated, it may be filtered to ensure a clear, particle free appearance. The filter equipment used, such as the plate and frame type, is common to that generally used in industry. Homogenizing and emulsification are conducted on some preparations to give them a more uniform consistency using colloid mills, homogenizers, or a combination of both.

Ointments, fatty preparations of semisolid consistency which melt when applied to skin, are manufactured in same manner as liquids except that they may be passed through an ointment mill of the roller or rotor-and-stator type. The former type consists of parallel rollers set to close tolerances whereas the latter type consists essentially of a high-speed rotor and stator enclosed in a head which may be jacketed for heating and cooling.

Suppositories can also be considered as a semi-solid product. Classified according to their vehicle or base, the common types are cocoa butter, glycerinated gelatin, glycerin, and polyethylene glycols. Some of these types are made by mixing active ingredients with the grated base and then compressing in manual or automatic machines.

Others may be formed by mixing active ingredients with a molten base and pouring the resulting mixture into molds.

Where liquid injectable products are manufactured, there is an extreme need for maintaining aseptic conditions. Kirk-Othmer reports that "Areas reserved for compounding and filling are usually small, enclosed, and constructed and furnished in such a manner as to facilitate cleaning. In some installations where disinfectant sprays are employed, the ceiling is sloped toward one end to obviate dripping of condensed vapors. Control of air purity, temperature, and humidity is a necessary adjunct to other measures designed to support aseptic operations, and rooms are generally maintained under slight positive pressure to prevent influx in air from unconditioned spaces." These and other measures are taken to ensure that bacteria in the area are kept to a minimum and "In most manufacturing laboratories a periodic check is made of the bacterial count of the air at different stations."

Though more a chemical unit operation than a procedure unique to the industry, extraction must be considered an important operation in manufacturing pharmacy. Essentially, it involves the grinding, possibly drying, and the charging into a closed vessel of animal or plant tissue. Solvents are introduced which are capable of dissolving desired active ingredients contained in the tissue. The solution is then recovered from waste material by filtration, centrifugation, heat vacuum evaporation, or a combination of these methods.

Packaging⁽¹⁾

The pharmaceutical industry uses about every form of packaging available to protect products against damage, contamination, pilferage, and decomposition. Depending upon the particular nature of the medication prepared, these operations may involve bag filling with powders, bottle filling with pills or liquids, blister sealing, the filling of aerosols, and others. The procedures and equipment used for most products do not have unusual characteristics which make them unique to this industry. Some unique methods are used, however, for the filling of ampuls and vials.

Filling of ampuls or vials with liquids is done with either single fill or multiple fill equipment. The hypodermic syringe is the basis for single-fill equipment. Multiple-fill apparatus are of various designs but all have the purpose of placing a precise quantity of medication into a receiving container. Prior to sealing ampuls, a jet of steam may be used to remove droplets remaining on the lip, or a warming flame may be used to evaporate residual moisture. The ampuls then pass a cross-fire of higher temperature sealing flames, and finally pass through annealing flames which relieve stresses in the glass.

Filling of dry powders into ampuls or vials is often accomplished in a small hood with sleeved outlets into which the operator inserts his gloved hands (i.e. a glove box). The operation may be done manually or by means of an automatic feeder but in any case may be completely enclosed.

Specific Operations, Exposures, and Controls

Compressing Machines

In general, compressing machines for tablet production, whether of single punch or rotary head construction, are designed to produce a maximum number of tablets in a minimum amount of time. These machines operate in the following sequence of events: (1) the powdered ingredients are gravity-fed from a hopper into a hole in a flat surface, (2) a scraper removes excess material from the flat surface, leaving the hole full of the preparation, (3) a plunger possibly subjects the material to precompression prior to final compaction, (4) applications of pressure form hardened particles and promote bonding, and (5) the finished tablet is ejected down a short chute to a collection container. Excess powder scraped from the surface is sent down another chute to a separate container.

These actions of the machine, conducted at high velocity, can create dust problems, problems which would appear to be fully appreciated. By reviewing periodicals of 1968⁽⁹⁾, it was found that advertisements for such machinery clearly showed series of flexible hose type suction devices incorporated into their design for dust control. The same periodicals, published in 1972-1973, contained advertisements for compressing machines almost identical to those shown in 1968. In these latter ads, however, the machines were seen to not only have the suction tubes, but also to have full plexiglass enclosures over all parts from which dust may be generated. These parts not only included those on or by which the tablets were actually made, but also the various chutes for finished tablets and excess powders.

The fact that commercially available machinery for such operations inherently contain full enclosures and local exhaust ventilation systems in their design indicates that engineering controls are fully available and utilized. The nature of the operation and the controls installed suggest the controls must be considered adequate when used.

There is one feature of the use of these machines which is worthy of note, and this concerns the fact that, since they are often used for batch operations, there is sometimes a requirement that the operator manually fill the bin above a machine⁽¹⁰⁾. It is not unusual to consider that the pouring of a fine powder from one container to another may release some of the product to the atmosphere. The fact that such exposures would be infrequent, might be controlled by general ventilation or an extension of the local exhaust controls installed nearby, and would easily be observed if they were significant, leads to the conclusion, however, that there is no need for any sort of research into the matter.

Rotating Pan Use

Rotating pans are used for tablet coating purposes. Such equipment primarily consists of a metal "pan" resembling a small cement mixer tilted

at some angle, or a canvas-lined polishing pan similarly mounted. To minimize dust releases, dry coatings applied, and dry the pan after wet cleaning methods, such units are provided exhaust systems to pull air through the pan opening and the entire bed of tablets. The ACGIH ventilation manual⁽¹¹⁾ recommends a face velocity of 100-150 fpm through the pan opening and a minimum transport velocity of 3000 fpm. Where heated air is supplied to the pan, it suggests "add volume of heated air to exhaust." Considering that the substances added to the pans include talc (to prevent sticking) and usually innocuous syrups (e.g., sugar, chocolate, and the like), and considering the nature of the operation, it can be concluded that controls for this operation are available, adequate, and indeed necessary to remove fines which would flaw the finish of tablets.

Capsule Filling Machines

Kirk-Othmer generally reports of hard-capsule manufacturing machines that "The precision of measurement with which the modern capsule machine produces capsules complements the remarkable accuracy of the modern capsule-filling machine. Here precise dimensions are essential." This comment, together with the comment that the process is completely automatic, suggests that excesses of ingredients are unlikely to be released from the operation. Nevertheless, it is further noted that capsule bodies are filled from a drug hopper and are often "blown dust-free" after filling. The fact that they need be cleaned in this or some other manner suggests that some dust is evolved from the operation.

In soft capsule making a rotary die process is used in which two continuous gelatin ribbons are fed between dies that revolve toward each other to form capsules at their points of convergence. An injection wedge at the last instant injects a measured quantity of the product into the closing capsule, and the capsule is then pressure-sealed.

By reviewing advertisements in trade magazines⁽⁹⁾ for precise descriptions of the equipment utilized, it was found that at least one manufacturer of automatic capsule filling machines featured that their units were "totally enclosed, ultra-hygienic, (and) anti-dust." An inspection of an included picture demonstrated that, as reported, all operating parts of the machine were surrounded with transparent, sliding panels. This indicates that control of airborne contaminants has been given consideration and can most likely be adequately achieved for these types of machines in general with applications of basic engineering control principles.

Mixers, Blenders, and Other Common Operations and Equipment

The literature contains numerous references to the use of mixers and blenders for preparing solid or semi-solid formulations of proper and uniform consistency. The types of machinery used are similar to those commonly used throughout industry and do not warrant any special discussion concerning use in the pharmaceutical industry. That controls may be necessary for such units is evidenced by the statement of Gerhart

et al. (7) concerning a production line for oral contraceptives. They note, "we are currently investigating the use of closed mixers, or processors, as opposed to our present open mixers. These would process larger formulas, and require less labor and material handling than the present system. A reduction of required labor and exposure to the product would carry important personnel considerations.

Numerous other types of equipment are used and operations conducted which are similar to those commonly conducted in other industries and which also do not appear to require any special consideration when used in this industry. Among these are laboratory operations, materials handling operations, open-surface tank use, the use of dryers for wet granulations, chemical synthesis in "closed" systems, cleaning and maintenance, etc.

Overall Discussion and Conclusions

This general overview of the industrial hygiene problems of the pharmaceutical industry leads to conclusions that are not in any way surprising. The most significant of these is clearly stated by the ILO(12), i.e. "The production of pharmaceutical preparations in large modern chemical factories does not involve any special dangers for employees working there. The experiences of the chemical laboratory and the results of the toxicological and pharmacological tests have supplied detailed knowledge of the substances handled."

Whether engineering controls are available and/or adequate for controlling exposures is a separate issue however. The paper of Gerhart et al. indicates that respirators are often primarily relied upon to reduce vapor or dust exposures, and protective clothing and devices relied upon to reduce skin and eye contact. Indeed, besides the notation that air conditioning "air exchange rates were chosen to minimize the concentration of airborne drug particles throughout the (production) area, and to facilitate solvent removal," there are no indications that engineering controls were used. It is specifically stated, furthermore, that all employees were required to wear dust masks in the production areas except for those working with solvents. These latter personnel were provided self-contained breathing apparatus.

Taking into consideration the fact that no significant exposure problems were noted from operations being unique to the industry, and that respirators are nevertheless necessary to control exposures, we are left with the overall conclusions that the equipment and operations which require further study are those which are common to other industries.

Summary of Operations Requiring Study

The equipment and operations identified in this evaluation as requiring further study are:

Chemical Processes
Cleaning and Maintenance
Dryer Use
Grinding, Crushing, and Screening
Laboratory Operations
Materials Handling
Open-Surface Tank Use
Spraying

3.3 PLASTIC AND FOAM MANUFACTURING

Introduction

A plastic essentially consists of an organic substance of large molecular weight which is solid in its finished state but which at some stage of production can be shaped by flow. The terms plastic and resin are used in overlapping senses, but resin applies more specifically to chemically homogenous polymers used as starting materials while plastics signifies the final solid product which may contain numerous additives.

The ingredients added to basic chemical resins include plasticizers, fillers, dyes and pigments, stabilizers, and mold lubricants. Lefaux⁽¹³⁾ devotes an entire book to a discussion of the toxicology of plastics and the substances used to manufacture them. Literally hundreds of toxic substances are described and a discussion given of how and why they are used and the hazards they present to workers. A review of this text quickly confirms the validity of placing the plastics industry high on a list of industries which utilize large numbers and varieties of hazardous substances. The presence of literally hundreds of reports and papers on the subject in the literature further confirms this conclusion.

Processes and Operations

Lefaux and others⁽¹⁴⁻¹⁷⁾ describe the principles and methods of processing resins and plastics in a similar manner, and it appears that the operations conducted within the industry can be generally characterized by those conducted in two major stages of production. The first of these involves the synthesis of monomers from basic elements and/or petroleum feedstock, and the polymerization or condensation of the monomers into resins. The specific operations and processes involved can be considered typical closed-system chemical processes as conducted by the chemical process industries in general.

The second major stage of manufacturing must be considered to be of primary concern in any discussion of exposure hazards. It is here that polymeric compounds are converted into finished products using methods which require a greater degree of active participation by employees. Specifically, the operations involved may include drying, to drive off solvents used in solution polymerization; grinding, to powder granules of resins or additives; measuring and blending of various

fillers, plasticizers, antioxidants, colorants, flame retardants, and stabilizers; mixing and blending of additives into the plastic; and molding and other processing methods for forming finished articles.

The "conversion" methods which are somewhat unique to the industry are those by which finished articles are prepared. These methods include blow molding, injection molding, compression molding, extrusion, calendering, casting, coating, forming, foaming, laminating, and thermofusion. These are described in the following.

Blow molding involves the extrusion of a section of tubing into an open mold, the closing of the mold, and subsequent pressurization of the interior of the tubing with air or steam. This sequence of events causes the tubing to conform to the configuration of the mold and is often used for manufacturing bottles and similar hollow articles.

Injection-molding involves the charging of the plastic into a cylindrical chamber and the application of heat and pressure to force the fluid mass into a mold. In the past, the method was used primarily for the manufacture of small articles but presently is used for large objects also.

Compression molding involves application of heat and/or pressure to force plastic to flow into, fill, and conform to the shape of a cavity. For some thermosetting substances molded with pressure only, the product is subsequently cured in an oven.

For continuous manufacturing of tubes, rods, sheets, or films, extrusion or calendering may be used. In extrusion, the polymer is propelled continuously along a screw through regions of high temperature and pressure where it is melted, compacted, and finally forced through a shaped die. Calendering involves the passing of a granular resin or a thick plastic sheet through pairs of highly polished and heated rolls under high pressure.

A variety of casting methods are used. The simplest, as used in the casting of metal articles, involves pouring a liquid material into a mold and solidifying it by physical or chemical means. Casting of thermosetting resins and thermofusion techniques for thermoplastic resins involves the filling of a mold and its subsequent placement in an oven for curing or fusion. Cylindrical articles such as drums and pipes may be made by rotating a cylindrical metal mold charged with granular polymer. In this process, the granules are fused by applying heat to the outside of the rotating mold.

Films, such as photographic film and cellophane, may be formed by flowing or spraying a solution of the polymer onto an extremely smooth surface in the form of a large polished wheel or, occasionally, a metal belt or band. After the solvent has evaporated (or, in the case of cellophane, the polymer has coagulated) the film is stripped from the casting surface.

Coating processes include "dipping" forms into open-surface tanks and "slush molding." In this latter process, a viscous latex or "slush" of partly plasticized material is poured into a hollow mold. The excess is then poured out, leaving a film which is heat treated and removed.

Often, paper and board used in packaging and box-making respectively are treated in a process having attributes of film forming and coating. This application involves the extrusion of a molten film of plastic onto the substrate under conditions in which the plastic adheres to it.

Lamination and low-pressure molding involve the impregnation of sheets with a dissolved thermosetting resin, the assembly of the individual sheets, and curing. A bag inflated with steam may be used for curing assemblies in the low-pressure molding process. Hot-press methods are used for lamination. The makeup of these assemblies may involve automatic machinery or the "wet lay-up" of work by hand. In this latter method, workers manually apply coatings of uncured resins and reinforcement materials to parts of a mold.

Forming of thermosetting resins involves heating a laminated sheet, shaping it quickly in a mold or around a form, and holding it in place with light pressure until it sets up. Vacuum forming is widely used for thermoplastic sheets. In this procedure, the sheet is warmed and laid across a hollow mold cavity. A vacuum drawn on the cavity causes the sheet to conform to the mold.

The production of plastic foams is accomplished by generating a gas in a fluid polymer. Thermoplastics can be foamed by the addition of a blowing agent, which decomposes to a gas at elevated temperature, or by the addition of an inert gas. The basic foam liquid generating machine consists of supply vessels, supply and recirculating lines, metering pumps, an integral valve block, a mixing head, nozzle, and solvent flush system. The resulting liquid is either poured into molds for subsequent curing, or is sprayed onto surfaces to be coated.

As reported by the Modern Plastics Encyclopedia⁽¹⁴⁾, other operations conducted in the industry which are of interest, but by no means unique to the industry, include mixing and compounding, parts removal, size reduction, slitting and winding, electroplating, flocking, dyeing, hot stamping, painting, printing, vacuum metalizing, materials handling, abrasive or laser machining, and others. Of interest is their comment that "virtually all materials handling systems used in plastics processing plants are of the pneumatic type, in which the material is conveyed in a stream of air under either negative (vacuum) or positive pressure or both."

Literature Review

Though numerous sources^(12,18,19,20) indicate that the majority of cured plastics have a low order of toxicity, they also note that hazards may be encountered from unreacted starting materials, the various

additives, and products of thermal decomposition. An exception to the rule of low toxicity is demonstrated by the isocyanates and other additives used to generate foams; toluene diisocyanate being of the highest concern from a hazard viewpoint. In the following, various papers which describe specific health hazards to workers and the means by which they have been controlled are reviewed to point out which specific operations have been noted as being hazardous.

Kingsley⁽²¹⁾ describes controls installed to reduce the high incidence of sensitization occurring in a plant processing epoxy resins. A principal design consideration was the separation of operations in which fumes were evolved from those in which dry plastics only were handled. "Uncured material could (thus) be confined to areas where special exhaust and handling equipment was available." The operations considered to be hazardous were "wet layup" and curing.

The area where wet plastics were handled was designed in the manner of a large water-wash booth. As he notes, "this area is 15 feet deep from the water tank to the outer edge of the hood. Exhaust capacity is 24,000 cubic feet per minute. All mixing and wet layup are done in this area." To ensure cleanliness, "not only is butcher paper used under the mold but the floor covering, a plastic film, is scraped off and replaced once a month."

Curing in this special area was sometimes conducted in a 50-ton press which also required an exhaust system. Thus, flexible ductwork was attached to the movable top of the press and sheet-metal panels were installed "to restrict the flow of air to the immediate area around the plastic."

For some work, a downdraft table with a rotating top was used. A feature of this unit was that air could be drawn across the work when a panel was removed from the front of a plenum to one side of the table. Baffles were used so that the down-draft flow was not stopped. Thus, the unit simultaneously worked as a side-draft hood and a down-draft table.

Key⁽¹⁸⁾ reports that enclosure of processes used in manufacturing is seldom practical but that they usually can be isolated "as in a resin-mixing booth. Exhaust ventilation can be provided at the booth or at imbedding and encapsulating machines. Push-pull ventilation is helpful in controlling fibrous glass reinforced plastics. Alternately, a housing and a vacuum cleaner line can be attached to sanders and routers."

Harris⁽¹⁹⁾ describes the case history of a worker who developed a dermatitis from powdered polymethyl methacrylate. The worker's job involved the sieving of the powder after its transfer from a drum to the sieve by means of a small hand scoop. Of interest is the observation that "this has also occurred as a result of cutting sheets of the polymer with a band-saw when a spray of fine powder or 'swarf' may be ejected over the man's hands ..."

Among the operations involving health hazards to workers, Eckardt and Hindin⁽²⁰⁾ include grinding, sanding and polishing epoxy resins; and sawing or grinding of asbestos-containing plastics.

Bourne and Milner⁽²²⁾ discuss the hazards from forming, molding, curing and finishing fiberglass articles containing polyester resins. The operations specifically described include spray-finishing, manual mixing of resin systems, compression molding, hand-sanding of articles, sanding on a continuous belt emery sander, polishing on soft textile buffing wheels, and dry-polishing on a buffing wheel. They note the use of spray-booths for spray operations, and "efficient exhaust ventilation apparatus" for the belt sander. The comment is made that "in the sanding rooms a fine dust of hardened polyester resin is given off, and it is almost impossible to obtain a completely dust-free atmosphere."

Lefaux⁽¹³⁾ reports for compression molding machines that "the mixtures of resins and various added substances may give off gases or vapours above the presses, and it is important to install in the workshops extraction systems over the presses capable of removing these gases and vapours as rapidly as they are produced. Simply airing or ventilating the workshops is not enough, and early symptoms of poisoning have been found in places without suction hoods." Other operations noted by Lefaux to require controls include spray-finishing, changing of filters, machining of plastics, and materials handling. For the latter he states "operations involving weighing powders or emptying them from containers involve risks depending on the toxic nature of the materials involved..." For control of such operations, he notes "a vertical air current between the worker and the materials being handled enables him to reach these while keeping his body the other side of the air curtain, and affords excellent protection."

Referring to the health hazards of "conversion processes" the ILO reports "in normal processing, chemical hazards are for all practical purposes non-existent. One would, however, advise provision of adequate ventilation in shops where moulding and extrusion machinery is operating. However, in the fabrication of polytetrafluoroethylene, there is a danger of overheated polymer decomposing and releasing highly toxic decomposition products that may cause polymer fume fever in exposed workers. In practice, (however) almost every case of polymer fume fever has been associated with smoking tobacco contaminated with traces of polytetrafluoroethylene."

Concerning polytetrafluoroethylene, Harris⁽²³⁾ writes "the monomer is of a low order of toxicity but its purification results in the production of highly toxic residues; the process is therefore fully enclosed and handling is by remote control for the protection of the worker."

The Michigan Department of Public Health,⁽²⁴⁾ writing of the hazards of polyurethane processing, reports "operations requiring ventilation are the pre-polymer preparation kettles, mixing equipment, mold filling stations, curing ovens, crush rolls, and waste disposal points." Though not included in the above list, it also addresses controls for spray-finishing operations. Additionally, it pictures exhaust hoods used for mold release spraying and crush rolls, and a pouring station in front

of a ventilated mold tunnel. The crush rolls appear similar to open-roll mill and calendering equipment in design.

Problems in controlling emissions of vinyl chloride monomer (VCM) in polyvinyl chloride (PVC) operations are the subject of a recent paper by Mack.⁽²⁵⁾ He notes that a typical PVC processing operation involves "first the high speed mixing and cooling of the dry blend, followed by transfer to a compounding process, and then final extrusion or molding of the product. At all stages of the process, PVC is heated and VCM is evolved."

Concerning the operations conducted in mixing and compounding areas, Mack notes that published documents show VCM levels are highest in these areas and that recent investigations have shown that atmospheric concentrations of VCM can be reduced "without significant engineering alterations to the plant, and with only minor modifications to the existing mixing process." Such systems are noted as being commercially available and adaptable to all existing PVC dry blending operations. From his description and an illustration, it is seen that the system consists of a typical mixer or cooler to which a cover is attached. To one side of the cover, a filtered air inlet is positioned. Near the center of the bowl, an exhaust port, connected to an aspirator unit, draws contaminated air away from the work area. As a refinement to the system, it is noted that air can be injected at specific points in the bowl to pass air upwards through the material and enhance stripping of VCM from the mix. To reduce operator attendance, and achieve maximum processing efficiency, the aspirator system can be integrated into automatic filling, mixing, and discharge cycles of the equipment.

Also reported is that "in most extrusion and molding operations with proper ventilation, the atmospheric monomer levels are generally lower (than in mixing and compounding areas), usually in the order of about 1 ppm. Nevertheless, the risk remains that unexpectedly high monomer concentrations can occur in any plant using PVC dry blend compounds containing high residual monomer levels." To be noted is that PVC compounds are extruded at relatively low temperatures, below 350°F, for reasons of thermal stability. Citing an advantage of stripping VCM from compounds before extrusion, he notes "ventilation of the extrusion area is usually more difficult because of the physical limitations presented by the process." Nevertheless, he reports "that some advanced design compounding extruders can also contribute to a general reduction of residual monomer levels in the finished compound. This is accomplished through vacuum venting ports located along the extruder barrel and by employing large quantities of air for pellet conveying and cooling."

Discussion and Conclusions

As previously noted, the operations and processes utilized for the synthesis of polymers from raw material feedstocks must be considered to involve what is termed "chemical processes" in this report, i.e. opera-

tions conducted within "closed-systems." Exposures which may occur from such operations would primarily result from "normal" leakage of system components, venting practices, cleaning and maintenance of equipment and similar conditions or situations. These operations are common to many industries and will therefore not be discussed separately for the plastics industry. That they may need some special attention in regards to their use in this particular industry is, however, evidenced by the toxicity of some of the typical raw materials used.

Most resins do not appear to present any significant exposure hazards per se. However, since some portion of the product may contain unreacted monomer, subsequent handling of resins may result in excessive exposures, as may operations which by heat or other physical means promote some degree of decomposition. Directly after polymerization, the concentrations of such unreacted materials can be considered to be higher than they will be in subsequent processing steps. Filtering, drying, grinding, and materials handling operations at this point therefore appear to require consideration for the necessity of engineering controls. If the resin is to be packaged and shipped before conversion processes are conducted, the filling and packaging operation must be included in the problems of materials handling.

The measuring, adding, mixing, and blending operations conducted in mixing and compounding areas are similar to "masterbatching" operations conducted in the rubber industry. In this, and that industry, these operations are considered to involve considerable potential for over-exposures. The specific operations conducted can be characterized as materials handling operations, and operations utilizing mixers and blenders for both solids and liquids. Again, these operations are common to numerous industries, but would appear to already have been given special attention in the plastics industry where such monomers as vinyl chloride may be evolved.

Some of the subsequent processing steps in "conversion workshops" are also similar to those conducted in the rubber industry. Specifically, these include compression molding, curing oven use, extrusion, and calendaring. Calender roll exhaust ventilation is a subject addressed by the Industrial Ventilation Manual⁽¹¹⁾ for rubber processing. Whether the same exhaust system performance criteria are necessary and/or adequate for the processing of various plastics is uncertain. The use of ovens and dryers is common in industry and does not appear to necessitate special consideration in this industry.

Whether extruders and compression molding machines (primarily those which heat the substance) require controls any more sophisticated than general mechanical ventilation is a subject of contention. Lefaux and Kingsley indicate that local exhaust ventilation is necessary. The ILO states that general ventilation is sufficient. Mack's comments indicate that the ILO may be right. He cites VCM concentrations of only 1 ppm as typical where general ventilation is used in the vicinity of extruders. While the temperatures applied are relatively low, the volatility of vinyl chloride is relatively high.

There is no indication in the literature that blow molding, injection molding, casting, forming, or thermofusion operations release amounts of airborne contaminants. However, since the plastic is heated in most of these, one must consider the possibility that some vapors or fumes may be released when heated chambers are opened or molten plastics or plastics dissolved in solvents are used in dip tanks, poured into molds, sprayed onto surfaces, etc.

The high-toxicity of the various isocyanates used in the manufacture of foam plastics obviously requires adequate control measures. In view of the above descriptions of operations, the comments of Reference 24 seem most appropriate and accurate. To reiterate, the statement of interest was that "operations requiring ventilation are the pre-polymer preparation kettles, mixing equipment, mold filling stations, curing ovens, crush rolls, and waste disposal points."

"Wet-layup" operations conducted manually with such materials as epoxy resins definitely require installation of special controls. Though Kingsley generally describes a production area which provides adequate control, specific ventilation system design criteria would not appear to be available in the literature for such operations.

A number of sources discuss the hazards of abrasive machining operations conducted upon polymeric substances. Controls for much of the equipment used in such operations have been described in various sources where metals are handled, but not for non-metallic substances.

In general, a review of the preceding information and the sources it was derived from does not allow any absolute conclusions to be drawn whether engineering controls are commonly available and/or adequate for all the numerous combinations of toxic chemicals and operations conducted in this industry. Concerning those operations conducted which are somewhat unique to the industry, the strong impression is, however, that serious problems do not exist, that various control measures have been adapted for use where necessary, and that real problems, such as the control of VCM, are receiving considerable attention, attention which is resulting in significant reductions in exposures.

A limited research effort to confirm or disprove this supposition may be in order. Of interest would be the determination of whether uncured plastics evolve excessive quantities of airborne contaminants at various stages of the production process which are somewhat unique to the industry, and whether adequate engineering controls exist for such operations. Particular operations to be studied would include those involving molding, curing, extrusion, calendaring, casting, foaming, wet lay-up, etc. A level of effort of 9 man-months and a time-frame of 6 months would probably be sufficient if personnel highly knowledgeable of the industry were utilized. The results of the survey would lead to the firm determination of whether specific engineering control research is necessary.

Other operations conducted are similar to those in other industries. As such, they are included in a following list of operations requiring further study. Of note is that the chemical processes and the materials handling operations conducted in the initial stage of production may be ideal candidates for specific study to develop control technology applicable to many industries. This, by virtue of the toxicity of some of the substances utilized or produced (e.g., vinyl chloride, epoxy resins, etc.).

Summary of Operations for Further Study

The list of operations and equipment which require further investigation in this report is as follows:

- Abrasive Machining (non-metals)
- Chemical Processes
- Cleaning and Maintenance
- Dryer and Oven Use
- Grinding, Crushing, and Screening
- Laboratory Operations
- Material Handling
- Non-Spray Application of Volatile Substances
- Open-Surface Tank Use
- Spray-finishing

3.4 PAINT AND COATINGS MANUFACTURING AND APPLICATION

Introduction

Paints, varnishes, and lacquers are widely and commonly employed throughout industry for coating objects with protective and/or decorative finishes. For 1975, it was estimated that over one billion gallons of such coatings would be manufactured with a dollar value approaching \$4 billion. The paint and coatings industry is comprised of some 1,200 companies having 1,600 plant locations. A large number of these companies are very small since the industry requires modest capital investment for equipment and relies on relatively simple and readily available technology. The four largest companies in the field account for about 22% of sales while the largest 50 account for 61% of sales. (26,27)

In general, the formulae for paints consist of three basic components. These include binders, solvents, and pigments to which various ingredients are added to impart special qualities. The binder forms the film, the solvent keeps the mixture fluid for ease of application, and the pigment provides color and improves film properties. Binders consist of natural resins, drying oils, or synthetic polymers. The solvent may be either water, as in water-based (latex) paints, or may be an organic solvent. Pigments consist of inorganic oxides, sulfates, carbonates, and chromates. (12,26)

Materials in Paint and Their Toxicity

It is estimated that approximately 2,000 different raw materials are used by the paint industry and that any given plant might keep as many as 600 of these in stock. Included among this vast number of raw materials are many which can and have been shown to cause occupationally related illness and disease. The ILO⁽¹²⁾ specifically describes some of the substances commonly used which are of concern.

Among binders it lists the use of shellac, linseed oil, alkyds, formaldehydes, polyesters, acrylics, epoxies, polyurethanes, vinyls, rubber derivatives and bitumens. Pigments include various metallic oxides, lithopone, calcium carbonate, magnesium silicate, barium sulphate, cadmium selenide and sulphide, ferric ferrocyanide, and carbon and lamp black. A wide range of hydrocarbons, alcohols, esters, ketones, and glycol esters are noted as being employed for solvents (toxic solvents such as benzene, tetrachloroethane and carbon tetrachloride have largely been eliminated from the industry though trichloroethylene is still used). Among special additives, mercury aryl compounds, pentachlorophenol or its sodium salt, and organic lead compounds are listed as fungicides. Metallic salts of organic acids, tricresyl-o-phosphate, zinc, aluminum, silica, asbestos fiber, antimony oxide and cadmium red are listed for other special purposes.

ILO reports lead pigments as being seldom used although a few yellows and greens may contain lead chromate. Metal primers, however, are noted as usually containing red lead. The EPA⁽²⁶⁾ reports that the use of red lead has been slowly increasing while the use of white lead has been rapidly decreasing. Estimated figures for 1975 show that 15.8 million pounds of red lead and 2.6 million pounds of white lead will be used this year.

Piper,⁽²⁸⁾ listed the various raw materials utilized in paints and discussed the toxicological effects of exposure. Thus, it is well documented that a large number of known toxic materials are used daily in the paint and coatings industry. Sources describing these materials and their toxicity are readily available and should be consulted for additional information.

Processes and Equipment

Bidlack and Fasig⁽²⁹⁾ provide a detailed description of the operations involved in manufacturing paint. In order, they discuss the receiving and storage of raw materials, the assembly of batch ingredients, mixing, grinding, thinning, tinting, filling, labeling, packing, storage, and shipping.

The operations involved in receiving and storage of raw materials are similar to those in numerous other industries. Essentially, they consist of materials handling operations, and the possible sampling and

analysis of substances in quality control laboratories. "Assembly of batch ingredients" includes the weighing or measuring out of the various ingredients and their placement in positions adjacent to the manufacturing unit.

Assembly is followed by the mixing of pigments and other additives with a sufficient amount of the vehicle (i.e., liquid binder and/or solvent) to wet the dry materials and produce a paste for grinding. When the paste is to be ground on roller mills, such mixing may be accomplished in low vats or tanks which are equipped with heavy stirrers. Lead mixers, dough mixers, and portable change-can or pony mixers are ordinarily used for this purpose. Pebble and ball mills or functionally similar devices may alternatively be used to combine mixing and grinding into one operation. It is generally recommended that the mixers be located so that pastes can flow by gravity to the grinding units and that piping facilities be provided to permit direct feeding of commonly used vehicles from metering or weighing devices to the mixing equipment.

Various types of grinders are used to reduce or disperse the paste to a fine and uniform consistency. The aforementioned roller mills consist of a number of hollow steel rollers which operate in a manner similar to that of all multi-roll mills; i.e., the substance is passed through closely spaced rollers which revolve at different speeds and in opposite directions to effect some degree of dispersion and/or size reduction. Ground paste is taken off the last roll by means of a scraper knife and either collected into a portable change can or pumped to thinning tanks. (29,30,31)

Pebble and ball mills depend on the contact between stone or porcelain pebbles and steel balls within revolving, horizontal cylinders. Water jackets are sometimes provided around the revolving mill for cooling purposes. The operating procedure for such units involves placing all pigments and a predetermined portion of vehicle into the mill and bolting down the loading hatch cover prior to revolution. The mill may be stopped periodically to allow for the insertion of additional vehicle. Access to the unit is through the aforementioned loading hatch and at a pouring spout on the opposite side of the cylinder. (29,31,32,33)

Other types of dispersion equipment used include high-speed stone mills, dough mixers, sand mills, high-speed dispersers, Uniroll mills, Kady mills, attritors, resonant mills, vibratory mills, and stator-rotor mills.

High-speed dispersion units basically consist of a tank in which is placed a high-speed stirrer with a special type of impeller. (31,34,35) High-speed stone mills contain a stationary stone and a rotating stone between which the pigment is subjected to a shearing action. (31) Dough mixers have two roughly S-shaped blades which overlap and rotate in opposite directions for dispersing very heavy pastes. (31,36) A sand mill is a cylinder containing sand and rotating impeller disks through which pigment slurries can be passed continuously (a screen retains sand in the mill). (31) Grinding in a stator-rotor mill is carried out in a

specially designed head at the end of a shaft.⁽³⁶⁾ An attritor mill is mounted vertically and contains balls which are agitated by means of a series of arms attached to a vertical shaft. In such a mill, the mixture can be passed through either on a batch or continuous basis.⁽³⁶⁾

A Uniroll mill is single, horizontal, water-cooled roller in an enclosure. A feeding hopper directs the mixture over the roll, and a vane bar, forced against the side of the roller, provides the grinding action. A scraper removes the treated paste from the roller face and directs it to an outlet spout.⁽³²⁾ Resonant mills are a somewhat recent development which consist of racks of tubes which contain a grinding or dispersing medium and which are vibrated at their resonant frequency.⁽³⁷⁾ A vibratory mill is similar to a high-speed disperser-but has the added feature that the grinding chamber is vibrated.⁽³⁸⁾ A Kady mill is also very similar to the high speed dispersion unit except for details of design and the fact the batch is generally smaller.⁽³⁹⁾

Thinning operations involve the further addition of vehicle to the paint formulation and follow the mixing and grinding processes. These operations may be performed either in stationary tanks or in portable change-cans. The stationary tanks have attached agitator units to mix the ground paste and vehicle thoroughly and uniformly. The portable tanks are placed under a change-can mixer unit for this purpose.

Tinting of batches involves the addition of tinting color to white bases or the adjustment of solid color bases which have been formulated as complete products.

The first step in the filling operation is the straining or filtering of the paint to remove any foreign material. This can be accomplished by the use of fabric or screen filters, or where high-grade finishes are desired, by the use of variable-speed centrifugal clarifiers. After such treatment, the paint is filled into cans which are subsequently sealed, labeled, packed, stored and/or shipped. Filling stations are usually small tanks which support hand filling operations or which are connected to filling machines by lengths of hose.

The paint industry is also involved with the manufacture of lacquers and varnishes, coatings which can be included in the generic term "paint" but which are produced by employing somewhat different equipment and procedures. For example, since lacquers differ from most other coatings in that the film dries entirely by evaporation, it is often impractical to manufacture them in the customary manner because the volatilization of the fast-evaporating solvents results in the deposition of a dry, solid film on equipment. Thus, the tanks, mixers, and other equipment used are usually of the completely closed variety to reduce solvent loss, ensure ease of clean-up, and provide fire safety.

"Varnish" consists of processed resins and oils, solvents, and metallic driers or catalysts. While some are produced without the application of heat, others require the heating of the oils and resins

in kettles at temperatures ranging from 450-625°F. The heating process results in the evolution of resin and oil decomposition products.

The methods of application of paints and coatings include brushing, dipping, roller coating, flow coating, and spraying. Production lines often use driers and ovens for "curing" purposes. The specific details of these operations are well-understood and common knowledge and, therefore, do not require further elaboration.

Literature Review-Exposures and Controls

Stern and Horowitz⁽⁴⁰⁾ report that "in the paint factory, dust exposures occur primarily at the mixers, ball or pebble mills and varnish kettles, and in the handling of bags of pigments, extenders, and resins for use in the mixers. A lesser exposure occurs in the handling and mixing of tinting pigments." Concerning vapor exposures, they state "the principal vapor exposures in paint manufacture occur at the reducing (thinning) and tinting operations, in can filling, in cutting nitrocellulose and resins and in the cleaning of equipment with a solvent. Vapor exposures also result from leakage from pump lines, meters, pumps, filters, etc. A small steady drip can allow a whole workroom's atmosphere to become charged with solvent vapor."

Stern and Horowitz discuss various exposures and their controls in detail and make some observations and recommendations apropos for many industries. Dumping bags, discarding empty bags and adding less than full bag quantities by means of a scoop are noted as sources of dust. Recommended controls include specially designed hoods over the top of mixers and ball mill loading spouts, covers with hinged sections for access to open-top mixers (with a 200 fpm downdraft through the opening), and/or lateral draft hoods near loading openings and at floor level chutes. Exhaust hoods over mills from which solvents are evaporated; general mechanical ventilation for can filling, reducing, and "churning" rooms; local exhaust of open-surface tanks and can filling operations involving lacquers and varnishes; and use of toxic solids in pellet form are recommended for other vapor and dust sources.

Bidlack and Fasig agree with the above and state "some provision for dust removal is desirable when dry pigments or powders are being handled. This can be accomplished by having exhaust fans so placed that the air is drawn over the mixing equipment and away from the operator and carried to the outside atmosphere, or by means of a direct-suction system which has openings mounted over each mixing unit so that the dust is directly exhausted therefrom." They also discuss fume recovery systems in varnish plants. From their descriptions and illustrations of typical plants, it is evident that adequate fume control technology and equipment for these processes are available. They not only address the control and recovery of vapors from heated kettles but also those from thinning tanks.

Patty⁽⁴¹⁾ indicates that "the mixing of dry pigments with oils and varnishes constitutes the principal health hazard of this industry." He

notes that various pigments are purchased in paper sacks and "a dangerous dust exposure occurs when the pigments are added to the mixers unless exhaust ventilation is used."

Freriks⁽³⁹⁾ addresses the hazards associated with the use of flammable solvents in the paint industry. Since lower flammable limits are generally well above toxic concentrations in air, his comments are applicable. He reports "it is commonly accepted today that a positive air movement equal to about one cubic foot per minute per square foot of floor space is adequate. Since solvent vapors are heavier than air the suction should be within a few inches of the floor. Exhaust and make-up air vents should be located to sweep the area of vapors."

Concerning dispersion equipment, Freriks reports that the too costly and too slow ball mill is being replaced by the high speed dispersion mill, the sand grinder, the attritor, and to some extent, by the Kady mill. For the high speed dispersion mill, it is said that unless local ventilation is used, the mill can release flammable vapors. This latter statement is also made for sand mills and continuous attritors. For batch attritors and Kady mills, it is noted that they are covered during operation and present no hazard greater than a covered tank of paint.

Arnstein⁽⁴²⁾ describes several factors to be considered when installing and maintaining a pumping system in a paint plant. Of interest is that the toxicity of the substance being handled and the leak-resistance of the system components are not mentioned.

Martens⁽⁴³⁾ reports that water-base paints are growing in popularity in industrial applications because of the principal reasons of "reduction of the fire hazard, toxic solvents, and air pollution." For example, in the area of ambient air quality, Los Angeles County officials⁽²⁶⁾ estimate that the application of paint contributes 360 tons of hydrocarbons per day to total organic emissions.

The hazards associated with application techniques are well appreciated and, again, do not require further elaboration other than to say that non-spray application techniques and drier use may expose workers to solvent vapors, and spray techniques expose them to the entire paint formulation.

Discussion and Conclusions

The paint and coatings industry relies upon relatively simple technology and utilizes equipment and procedures which generally require modest capital investment. These equipment and procedures do not include any which are unique to the industry, but rather, consist of those which are very commonly utilized or conducted in a wide variety of other industries. Consequently, there does not appear, at this time, to be any reason to investigate this industry separately and specifically to determine the availability and adequacy of engineering controls.

The large number of potentially toxic substances used in the industry, and the lack of specific data to identify the exposures which occur, does however suggest that some sort of exploratory study is warranted to determine the nature and extent of occupational exposure to recognized hazardous substances and of any observable health effects that can be associated with exposure to occupational environments in the industry. Such a study would provide sufficient information to permit responsible evaluation of the need for more thorough and rigorous investigations and might concentrate on all toxic substances, not only those regulated by OSHA.

Since the objective of this report is to investigate the availability and adequacy of engineering controls where a need for their use can be identified, the recommendation of such a study is beyond the scope of this work. Therefore, the following list simply identifies those operation categories which are pertinent to the industry, but which, by reason of their commonness, require study on a broader scale.

Summary of Operations for Further Study

The list of operations and equipment which are to be further investigated in this report is as follows:

- Chemical Processes
- Cleaning and Maintenance
- Dryer and Oven Use
- Grinding, Crushing, and Screening
- Laboratory Operations
- Material Handling
- Non-Spray Application of Volatile Substances
- Open-Surface Tank Use
- Spray-Finishing Operations

3.5 RUBBER PRODUCTION

Introduction

The rubber industry is large and heterogeneous, involving a wide variety of processes, operations, and substances. Many of the toxic substances encountered play a role at any number of points in the compounding of rubber, either natural or synthetic.

The rubber industry, according to McCormick⁽⁴⁴⁾, involves "not only the conversion of the natural and synthetic polymers into usable articles, but the manufacture of chemicals, plastics, and numerous other materials."

Morris⁽⁴⁵⁾ writes, "The rubber industry is one of America's largest industries, in which great numbers of workers are employed in compounding, mixing, fabricating, and sheeting the various rubber compounds."

The processes and operations employed in rubber compounding and fabrication include those which are common to many industries and those which are found primarily in the rubber industry. Among the former can be included closed-system chemical processes, materials handling, abrasive machining, drying, and others. The latter include vulcanization, mastication/mixing, and formation. The specific processes and operations involved are discussed and described in the following.

Stephenson⁽⁴⁷⁾ relates that natural "rubber is a natural exudation from various plants when they are cut or injured. The ordinary rubber comes from the tree 'Heavea braziliensis', a native of South America which is now grown commercially chiefly in the Far East. Two other forms of natural rubber are also known, namely, guttapercha and balata. All three of these natural rubbers are polymers of isoprene (and) 2-methyl-1,3-butadiene" and constitute the basic feedstock for production of natural rubber articles.

Stephenson also gives an account of the processes by which various types of rubbers are synthesized. The emulsion polymerization process for butadiene-styrene copolymer (former GR-S, now usually called SBR), the most commonly used rubber, is described as consisting of a series of reactors, a blowdown tank, a pressure flash tank, a vacuum flash tank, and stripping columns. Nitrile rubbers are said to be produced in a similar process and the process trains for other rubbers are generally noted as utilizing similar and typical chemical processing equipment. Exceptions to this generalization, however, are found to include the use of tunnel driers during the production of solid butyl rubber and ethylene-propylene elastomers.

Mallette⁽⁴⁸⁾ writes, "The points of potential exposure in these processes are in the handling of raw materials, coagulation, centrifugation, and drying." With regard to controls in the synthetic rubber plant, he says, "Adequate local and general exhaust ventilation must be provided for coagulating tanks and centrifuges. The escape of vapor from the dryers can best be prevented by maintaining a slight negative pressure within them. It may be necessary to provide hoods over the dryer outlets to control vapors of styrene and other substances driven off at this point."

McCormick⁽⁴⁹⁾ gives a comprehensive review of the hydrocarbons encountered in the synthetic rubber industry, specifically styrene-butadiene rubbers, referred to in his paper as GR-S (Government Rubber-Styrene). Both butadiene and styrene are said to be produced, stored, transported, and handled in closed systems, and neither substance is considered to be more than mildly hazardous.* However, some of the minor constituents, specifically dinitrochlorobenzene, sodium sulfide, and triphenylphosphite are noted to pose potential dangers. The author states that "precautions must be taken to prevent skin contact [with dinitrochlorobenzene]," and recommends process ventilation to control

*These substances may be hazardous according to more recent information.

the sodium sulfide hazard. (The danger here is from the production of hydrogen sulfide in the presence of sulfide). Process ventilation is also recommended for the triphenyl phosphate which produces phenol upon hydrolysis.

Open-roll mills, enclosed Banbury mixers or Gordan Plasticators are employed to "breakdown" rubber elastomers prior to compounding, the Banbury being the most commonly used for this purpose. The open-roll mill is usually ventilated with a semi-enclosing hood with a specific face velocity. Ventilatory control for Banbury mixers is a subject addressed by the ACGIH ventilation manual.⁽¹¹⁾ Gordon Plasticators operate on an extrusion principle, with the raw material being forced through screens, around disks, and through a die by a rotating screw.

After breakdown, resins and pigments are added to the rubber in a process termed master-batching. In this operation, some of the more hazardous materials are introduced into the rubber, including solvents, carbon-black, sulfur, and organic accelerators. To provide for homogeneity of the additives in the rubber, the components are mixed on a mill or in a Banbury. If a mill is used, a considerable amount of manual handling may be required to help pass the rubber through the rollers. The adequacy of any ventilation system is more important at this point due to the increased number of potentially toxic materials added in this procedure. Since the rubber is handled in batches, the exhaust systems must be capable of handling sudden, intense dust and vapor loadings.

Master-batching is initiated in a weighing room where the accelerators, pigments, anti-oxidants, and other components are stored, weighed, and added to the rubber. These steps are simply materials handling operations but may result in significant dust and vapor levels. In writing on the use of rubber additives, Bourne⁽⁵⁰⁾ notes that "The main problem areas discovered were: mixing or milling of rubber stocks with the additives, curing or vulcanizing, and dusting of semifinished and finished products." Almost 600 different additives were encountered in a survey of 140 plants, involving 19,400 workers.

Schwartz⁽⁵¹⁾ reports that "Dermatitis has been known to exist in the rubber industry for a long time, the terms 'rubber itch' and 'rubber poisoning' being commonly applied to this condition." He refers to chlorides, stearic acid, lead oxide, litharge, yellow pigment, arsenic, carbon disulphide, and many others. In reference to the National Safety Council Transactions, Schwartz reports that "compounding is rated as one of the most hazardous processes in the industry, and that insurance companies class compounders among those whose mortality is expected to run from 50 percent to 100 percent above the average. Mixing room workers are thought to be exposed to similar hazardous compounds."

Once the rubber has been properly mixed with additives, it is either stored for future use, or employed directly as stock for calenders or extruders. A calender is generally a multi-roll mill which can be

adjusted to produce various thicknesses of rubber sheeting, impregnate fabric with rubber, or skin rubber to one side of a fabric. Again, a moderate degree of rubber handling is required by the mill operator, who may be exposed to solvent fumes. The ACGIH manual contains hood design criteria to control such exposures.

Extruders, which function by forcing rubber through a die by a rotating steel screw, are used in stock preparation, as in the production of tire threads, or to form the basic product immediately, as in rubber band production. In either situation, the process is the same and will generally require handling by the operator. If extrusion takes place at high temperatures, fumes may be evolved in the operation. Excess talc, applied at this point to eliminate the stickiness of the rubber may result in excessive dust exposures.

Depending upon the article being manufactured, any number of machines and tasks may be involved to convert stock into its final, or nearly final, form before vulcanizing or curing. Tire-building operations, for example, are complex and generally require a high degree of manual handling, handling done in the presence of petroleum spirits used to keep the rubber fresh and workable.

The next step is curing, i.e. vulcanization, of the assembled product. This operation is achieved on several types of machines, including presses, autoclaves, pressure vulcanizers, hot water tanks, or Rotocures. Some of these are enclosed units, releasing gases and vapors solely when opened, or when improperly maintained, while others, such as the Rotocure, operate in a semi-open mode.

The mold cure is the most elementary operation. Here, the fabricated article is inserted between two halves of a mold which is then closed and heated to the vulcanizing temperature. After a specified time, the mold is opened and the article removed. It is precisely at this stage that vapors and fumes may be released to the environment. Of note is that toxic substances which were not originally present may be evolved because of the elevated temperatures.

In steam curing, the article is placed in an autoclave and exposed to steam at a specific pressure. For such operations the article must be preformed since no shaping occurs as when a mold is used. When an autoclave is opened after curing, a cloud of steam and toxic contaminants are released similar to the mold curing process. Not all curing operations are conducted in a batch. Where conveyor belting or packing is treated, units such as the Rotocure are utilized in a continuous operating mode.

Final finish operations involve an assortment of buffing, trimming, and inspection tasks highly specific to the product involved. Buffing may be considered as an abrasive machining operation from which an air-borne dust may be produced.

Engineering Controls

A review of the literature indicates that specific ventilation system design criteria for operations unique to the industry exist solely, in the general literature at least, for Banbury mixers and calenders. Other recommendations found were definitely of a more general nature. For example, where solvents are used, Greenburg and Moskiwitz⁽⁵²⁾ simply recommend the three standard methods of approach, i.e., (1) substitution, (2) general ventilation, and (3) local exhaust ventilation and give the substitution of toluene for benzene as an example of the first stratagem. When the work area is large, they report that general ventilation can be employed. If the work is localized and fixed, local ventilation is noted as probably being most effective. The ILO⁽¹²⁾ recommends "good general ventilation of areas where volatile materials are used," effective ventilation of process vessels prior to entrance for maintenance, and standard controls, such as gloves, aprons, and other protective garments. Particular problem areas within the rubber industry appear to be the formation and vulcanization stages of manufacturing. Given the controls recommended by the ACGIH for the calender mill, it would appear that similar controls may be necessary for open-roll mills, extruders, and other machines in this category. The nature of curing operations indicates that controls are also desirable for these processes.

Discussion and Conclusions

As is evident, a wide variety of operations are conducted in this industry, and industrial hygiene problems, both specific and non-specific to the materials and processes employed therein, must be considered to exist. Indeed, the nature of many methods used would regularly involve direct insult to the worker from an assortment of physical and toxic agents if proper control measures were not instituted.

Whether practical engineering control measures exist or are adequate for all the various operations unique to the industry involves questions which cannot be simply answered from this investigation. That it is likely that they do not, however, is evidenced by the fact that as a result of an agreement between the International Union of Rubber Workers (IURW) and the major tire manufacturers, Harvard University and the University of North Carolina are involved in a multi-million dollar effort to investigate the industry's problem areas. Though this investigation is limited to the tire industry, it can be assumed that many of the problems and solutions that are discovered and developed will be applicable to the industry as a whole.

The fact that such a large-scale effort is being conducted by the private sector leads to the conclusion that it is not at this time necessary for NIOSH to participate in research activities which may parallel or repeat work currently being conducted. It is therefore recommended that NIOSH attempt to keep abreast of the findings and results of these activities, encourage publication and dissemination of worthwhile findings to the entire industry, and if then deemed necessary, support research to fill any data gaps which become evident.

Summary of Operations Requiring Study

In the above, the opinion has been expressed that current activities of the rubber industry itself suggest a "wait and see" attitude is appropriate on the part of NIOSH. The operations and processes which at present warrant further study, therefore, are those which are common to many industries; these being:

- Abrasive Machining
- Chemical Processes
- Cleaning and Maintenance*
- Dryer and Oven Use
- Grinding, Crushing, and Screening
- Laboratory Operations*
- Material Handling
- Open-Surface Tank Use*
- Spray-Finishing*

3.6 PESTICIDE MANUFACTURING AND APPLICATION

Introduction

Pesticides are agents used to destroy the plant and animal pests of man. These compounds encompass many different classes of chemicals and act upon numerous target pests; hence, the more specific terms insecticide, herbicide, rodenticide, fungicide, nematocide, molluscicide, etc. used to describe them. In addition to agricultural uses, these substances are employed in a wide variety of other pursuits such as structural pest control, wood treatment, mothproofing, and maintenance of utility and transportation rights-of-way. Thus, potential occupational exposures to pesticides are numerous and varied. (12)

For the purposes of this study, three major aspects of pesticide manufacture and use are of concern: manufacture of the active ingredient; formulation of the pesticide product; and application.

Pesticide Manufacturing

The first stage of the pesticide industry involves the synthesis of the active ingredients. The specific operations and processes involved are generally closed-system chemical syntheses as practiced by the chemical process industries. Most of the producers of basic pesticides, indeed, are multi-product chemical companies that produce a variety of products⁽⁵³⁾. The technical grade pesticide compound produced is usually transported in bulk in liquid form (tank cars or barrels) or as a powder or dust (in barrels or bags) to be mixed with other ingredients into a finished pesticide product.

* The industry evaluation did not specifically demonstrate that these operation categories are involved in this industry. Nevertheless, they are included either by reason of the logicity of doing so when the nature of the industry is given consideration, or because of personal experience of the authors in noting their use.

Formulation of Product

In addition to one or more active ingredients or toxicants, a trade-name pesticide product contains synergists, surface-active agents, diluents, and other substances. The mixing of these ingredients is the formulation stage.

The compounding of solid insecticides involves the addition of liquid or solid toxicant to a dust carrier such as clay dust, talc, lime, or silica. In the case of the former, liquid toxicant is spray during blending, and the wetted mixture passed through several mixing stages (usually through ribbon blenders) and/or ground in a pulverizer. (It should be noted that the wetted mixture, although containing as much as 50% liquid by weight, acts as a solid because of the porosity of the solid carrier.) The wetted dust is then conveyed to a holding bin for packaging into bags, boxes or other containers. The insecticide Toxaphene is produced in this manner. The active ingredient, melted and mixed together with kerosene, is sprayed into clay dust and blended thoroughly. (54)

Active ingredients in solid form are ground and mixed with a carrier in several passes through standard grinding and size-reduction equipment. An example of this process is the compounding of DDT dust. (54)* Emptied from sacks into a hopper, DDT flakes are passed through a crusher and a pulverizer where finely ground silica (a stabilizing agent) is added. After thorough mixing in a ribbon blender, the DDT is conveyed to a barrel-filling unit where it is packed for aging. The aged material is blended further and finely ground in several stages (utilizing high-speed grinding mills and high-pressure air mills and cyclone separators). Finally, the product is packed into barrels for shipment.

Liquid products can be formulated as a solution, emulsion or suspension. DDT, for example, was often formulated as a liquid containing (54) the active ingredient, two emulsifying agents, and an organic solvent. Formulation of such products generally simply involves addition of ingredients to an agitated tank and subsequent packaging operations.

Pesticide Application

Application operations involve the preparation of the pesticide product into a final form for distribution, the transfer of the product to the application equipment, and the actual application of the pesticide. The specific nature of these operations is determined by the properties

* Although DDT is no longer in use in the U.S. and is produced by only one pesticide company, the formulation process is felt to be representative of the procedures for other pesticide products formulated from solid toxicants.

of the formulation, the nature of the target pest, and the site of application.

The EPA recognizes 15 distinct physical forms of pesticide products ranging from crystals, granules, and wettable powders to emulsions, liquids, and pressurized gases and aerosols.⁽⁵⁵⁾ Many of these forms require some pre-application preparation in accordance with manufacturers' instructions. Typically, this involves the mixing of the concentrated product with a diluent or vehicle such as food (use as bait), water, kerosene, oils, or organic solvents.⁽¹²⁾ Since most pesticides are still handled in 5 to 50 pound bags and cartons or 1 to 5 gallon containers, these mixing operations, and subsequent transfer operations, may involve considerable manual handling, although the use of closed systems for transfer to application equipment must be noted as increasing.

Application equipment for pesticides include mist blowers, hydraulic ground sprayers, backpack and handheld sprayers, specially outfitted aircraft, dusters, soil injectors and incorporators, and aerosol bombs.

Spraying is the most common method of pesticide application. For organic insecticides, concentrated sprays (toxicant 10-95% of mixture) are being widely used. The development of air blast nozzles for pesticide spray equipment has made this technique possible since the droplet size produced by these nozzles is 30-80 μ compared with the 200-500 μ droplets produced by hydraulic nozzles.⁽⁵⁴⁾ Concentrated sprays are also conducive to aerial application, the most economical way to treat large tracts of land with spray, dust, or granules.⁽¹²⁾

Increasingly, farmers and others have been employing specially trained pest control applicators because of the cost of specialized equipment (such as airplanes) and the hazards of pesticide use. Only large-scale pest control concerns are likely to have specialized facilities for handling and mixing of pesticides, facilities equipped with suitable engineering controls. Smaller volume pesticide users, such as most pest-control operators and individual farmers, usually lack such facilities and must rely on respirators and protective clothing for exposure control.

Other Operations

Other occupational groups exposed to pesticides include harvesters of sprayed crops,⁽⁵⁶⁾ other agricultural workers that reenter fields too soon after pesticide application,⁽¹²⁾ and employees in food and other agricultural product processing plants.⁽¹²⁾ The disposal of unwanted pesticides and pesticide containers may also result in occupational exposures. For example, workers in pesticide container recycling operations (common in California) may be exposed.⁽⁵⁷⁾

Literature Search

According to Hamilton and Hardy⁽⁵⁸⁾, "it is the continuing objective of the chemical and agricultural industries to develop materials which

control specific categories of pests and have minimal potential for detrimental effects in man and other desirable animal and plant species. Unfortunately this goal has not yet been achieved, and examples of clinical intoxication continue to appear, usually as the result of accidents or incorrect methods of distribution and application." In many cases, these accidents result from disregard of instructions pertaining to the handling or application of the active ingredients.

A very recent closing of a chemical plant in Virginia demonstrates not only the continuing occurrence of occupational exposures during synthesis of pesticide active ingredients, but also the possible serious effects of these exposures.⁽⁵⁹⁾ Following reports of illness among workers, state health officials visited a small plant manufacturing the active ingredients for a chlorinated hydrocarbon related to DDT, used in controlling banana pests, ants, and roaches. As reported by one of the visitors, "There was Kepone dust all over and piled up an inch deep in some places. Nobody was wearing proper safety gear, and I could tell just by looking at them that seven of the 10 workers there that day were sick. One could hardly stand up." Equipment in use was termed "kind of a Rube Goldberg contraption." Ex-employees reported numerous spills and leaks. One commented that, "the plant was filthy and there was Kepone all over the place, even on the picnic table in the gas station part where I'd eat." Health effects found in 110 workers tested ranged from high levels of the chemical in their blood (50% of the workers tested) to severe memory loss and liver damage (requiring hospitalization of 13). "A small group tested for effects on their reproductive systems was found to be sterile."

The complete lack of engineering controls and disregard of protective equipment in the plant reported upon in this incident must be noted as representing a rare situation in the industry. The report indicates that the serious occupational and environmental problems observed might have been avoided if "a more established chemical concern" had been manufacturing the chemical.⁽⁵⁹⁾ Nevertheless, the very fact that such a situation could be allowed to develop indicates a lack of understanding on the part of employers and employees alike of the hazards of toxic substances.

Wolf and Armstrong⁽⁶⁰⁾ studied the potential maximum exposures to DDT of workers in two plants formulating 50% water wettable DDT powder. Dermal and respiratory exposures (assuming no protective gear) were measured for four work situations: mixing, bagging, sewing of bags, and packing of bags into cartons. The potential maximum exposure was found to be greatest in the bagging operations in both plants. During bagging operations, powder was blown into the air during removal of filled bags from the spout and closure of the filler hole by a folded flap. Inadequate ventilation and periodic malfunction of the filler spout mechanism in one plant sometimes resulted in gross contamination of the operator. ("The authors have observed that these two problems are not uncommon in pesticide formulating plants.") The main exposure in the packing stations was powder blown from inside the carton as the worker pressed the bags into place. Of the four work situations monitored,

mixing of the various dry ingredients resulted in the lowest total exposure. In all operations, higher potential exposures were found in the plant observed to have the poorer ventilatory controls and house-keeping.

Calculated exposures when "recommended protective gear" was worn were determined to be 2.5 to 10 times less than the calculated potential maximum exposures (i.e., no respirator or protective clothing). Low levels of a DDT metabolite in urine of workers in these plants indicated that the protective gear actually worn* was effective. However, the authors reported the wearing of clothing which provides only minimum protection and non-use of a respirator are not particularly uncommon in formulating plants... Our observations in formulating plants indicate that, when workers are at the bagging station and not wearing respirators, it is almost impossible for them to avoid inhaling large quantities of the compound which is sometimes obviously present in high concentrations near the breathing zone."

Danielson⁽⁶¹⁾ addresses the air pollution aspects of insecticide formulation procedures. He comments that some of the sources emitting dust are bag packers, barrel fillers, hoppers, crushers, conveyors, blenders, mixing tanks, and grinding mills. He considers the crushing and grinding operations most hazardous and recommends maximum enclosure with indraft velocities of 400 fpm or higher. For the other operations, where dust is released at low velocities, velocities of 200 to 300 fpm are suggested through open areas in enclosures.

Inhalation and dermal exposures of 52 farmers engaged in seasonal spraying of apple orchards and vegetable and grain fields were studied by Jegier.⁽⁶²⁾ With respect to personal protective measures, 48% of the operators had no protection at all; 39% had head protection, 20% used cloth overalls, 27% used gloves, and only 11% used respirators. Bare hands were used during mixing by 21% of the operators, and 85% were observed to exercise "insufficient care" (e.g., disregarding wind direction during tank preparation). The total exposures of operators were nevertheless calculated to be less than 1% of the toxic dose for each insecticide used. "While the investigation did not indicate that spray operators were subjected to doses approaching acute toxic levels, field observations during the course of spray operations revealed a laxness in the attitude of the majority of spray operators towards cautious spraying practices."

California is the largest agricultural state in the U. S. and one of the largest state users of pesticides. Reports of occupational disease in California, including that resulting from agricultural chemicals, must be filed by the attending physician with the State Department of Industrial Relations. In 1957⁽⁶³⁾, 710 cases of occupational

* Rubber boots, cap, respirator, cloth overalls with long sleeves, and rubber gauntlet gloves.

disease (including one fatality) were attributed to pesticides. Of these, more than one-half involved cases of dermatitis, 251 cases involved systemic poisoning, and 52 cases involved respiratory illness. Workers in agriculture (both on farms and in services, including commercial ground and air spraying) had 60% of the reported occupational disease, 65% of the reported cases of systemic poisoning, and 53% of all reported dermatitis. Statistics⁽⁶⁴⁾ of disabling work injuries for 1970 in this state (i.e., those resulting in loss of time from work) include 216 (no fatalities) attributed to insecticides, sprays, and fumigants. Of these, 113 occurred on field crop, vegetable, orchard, and general farms, and 69 involved agricultural service workers (including commercial pest control operators.) Since the number of disabling injuries in 1957 was 340, it appears that advances in control of occupational exposures to pesticides in the 13 year period resulted in a net 36% reduction in disabling injuries. While this reduction is significant, it does not overshadow the fact that a substantial problem yet remains.

Discussion and Conclusions

The operations and processes of the pesticide industry are by no means unique; chemical processing, wet and dry mixing, bagging and materials handling, and spray application are common operations throughout industry. However, unlike many other industries, the pesticide industry predominantly produces or utilizes compounds of significant toxicity, many of which are not only hazardous when inhaled but also when in contact with the skin. The nature of end use is very widespread, occurring for the most part out-of-doors or in places (such as barns, grain storage bins, etc.) where traditional engineering controls such as process enclosure and exhaust ventilation are generally considered impracticable.

In its roles as regulator, the EPA has sought to protect the pesticide worker, as well as the environment. Occupational safety is a consideration during registration of both the active compound and the formulation. Restricted-use registrations issued for some pesticides are designed in large part to protect the applicator (only those with proper protective equipment and training are licensed to apply these products).

No unique problem areas requiring study by NIOSH were identified for this industry. Thus, the following list of operation categories simply encompasses those which are common to many industries.

Summary of Operations Requiring Study

The operation categories which are to be further studied in this report are:

- Chemical Processes
- Cleaning and Maintenance
- Grinding, Crushing and Screening

Material Handling
Open-Surface Tank Use
Spray Application

3.7 ADHESIVE MANUFACTURING AND APPLICATION

Introduction

In the United States, the adhesive manufacturing industry is highly fragmented with over 800 companies operating approximately 1200 plants. (65,66) Industrial end-users of adhesive products number in the hundreds of thousands. In both manufacturing and end-use applications, there are numerous opportunities for worker exposure to the toxic substances incorporated in many adhesive formulations.

Adhesive manufacturers can be classified by their position in the "raw materials to end-use" sequence. The three primary classifications are:

- Companies that produce raw materials for adhesives, but also manufacture limited quantities of finished products for outside distribution;
- Companies that purchase raw materials and specialize in the manufacture of finished adhesives for commercial distribution; and,
- Companies that purchase raw materials and manufacture finished adhesives for captive use in other products.

The first of these classifications encompasses the producers of natural and synthetic elastomers and resins. The manufacture of finished adhesives is not a major part of the plastics industry; however, the plastics industry is a primary contributor of substances for manufacturing adhesives.

The manufacturers of commercial adhesives comprise the most important classifications. A typical adhesive plant is very small compared to most other plants of the chemical process industries. The largest adhesive plants usually have work forces of about 100 people; while small 2- or 3-man operations are frequently encountered.

The third classification -- captive manufacturing -- also represents a major part of adhesive manufacturing. Most of these companies are of moderate to large size. The poor economics associated with small scale manufacturing is often incentive for small companies to purchase their finished adhesives.

The 1980 projection for domestic end-use of all types of adhesives has been set at nearly 5 billion pounds. (67) Applications cover a wide

range of areas which relate, either directly or indirectly, to nearly every aspect of the manufacturing industry in the U. S. The primary applications are:

1. In the conversion of forest products:
 - Plywood, veneer and particle board used in residential construction and durable goods.
 - Furniture, prefabricated structures and other wood products.
 - Paper and packaging such as boxes, bags and envelopes.
2. In the conversion of non-forest products:
 - Non-durable goods such as plastic laminates, tires, sealants, shoes, and apparel.
 - Durable goods such as glass insulation, automobiles and aircraft.
3. As replacements for conventional fasteners:
 - In interior and exterior construction.
 - In musical instruments and other consumer goods.
 - In sealing metal cans and other food industry packaging.

Therefore, both adhesive manufacturing and end-use applications have the potential for affecting large numbers of workers.

The chemical and physical processes associated with adhesives are best described for both manufacture and end-use applications separately.

Manufacturing Processes

Batch processing, rather than continuous processing, is the most common method of adhesive manufacture. Batches of 1000 gallons are considered large by industry standards. The single unit operation that is common throughout is mixing. In fact, various aspects of mixing comprise 80-90% of operations used in adhesive manufacture. (66)

The processing necessary in adhesive manufacture is best delineated by a discussion of each primary adhesive category. (68-71)

A. Animal Glues

Although manufactured by only 4 companies at the present time, glues derived from animal materials have been the foundation of the adhesive industry for several hundred years. Such adhesives are usually one-part systems supplied to industrial users as water-soluble dry flake. The manufacture of these glues from animal hide and bone involves several preparatory steps. Bones must be ground and hides must be cut, solvent-degreased and washed. The protein products from each must be extracted, filtered and further processed to final flake form.

B. Aqueous Adhesives

This category includes most one-part adhesives based on water soluble natural and synthetic materials.

(1) Natural Adhesives

- Starches are water-dispersible, natural polymers derived from grains and roots. Preparation of the raw materials for use in glues requires extraction, drying and milling. Moreover, additional starch-based glues-- such as oxidized starches and dextrans -- are formed by hydrolysis and repolymerization of the original starches. Many of these preparatory steps are carried out by the grain processing industry. The final glues vary from dry powders to liquid solutions.

- Soybean glues are manufactured by wetting, shearing, defoaming, dispersing, denaturing and finally crosslinking the original soybean materials. The grain processing industry is involved in this area also.

- Cellulosics are derived from the structural elements of plants such as cotton and wood pulp. Most require dissolution in organic solvents, but some are water soluble. Processing is similar to starches and soybean glues. The final form can be a solvent solution, powder or thermoplastic (hot melt).

- Milk, as the starting material for casein glue, must go through extraction and drying operations to produce the final powdered products.

(2) Synthetic Adhesives

Synthetic materials will account for most of the anticipated growth in adhesive manufacturing during the next 5 years.⁽⁷²⁾ However, this growth estimate includes all synthetic adhesives, not just the aqueous-based adhesives discussed here.

- Phenol resin adhesives are predominately the phenolformaldehyde glues as used in plywood manufacture. The phenol and formaldehyde are combined in batches to produce dry resins tailored to the needs of the user. Water dispersions are formed at the time of application.

- Polyvinyl acetate is polymerized and used as a dispersion of solid resin in water. This is the most widely used form of PVAC.

C. Solvent Adhesives

This category also includes adhesives based on natural and synthetic elastomers and resins. The use of organic solvents substantially increases exposures to toxic substances.

(1) Natural Adhesives

- Cellulosics requiring dissolution in organic solvents are also derived from the structural elements of plants such as cotton and wood pulp. As with water soluble cellulosics, these adhesives can be formed as solvent solutions, powders or thermoplastics.

- The rubber industry supplies raw materials to adhesives manufacturing. These include vulcanized and unvulcanized rubbers in latex solution and bulk form. Adhesives are prepared by mastication (milling) and mixing of rubbers with various additives such as tackifiers, resins, fillers, plasticizers and curing agents. Products are available in latex form, as solvent solutions and as mastics.

- Other natural hydrocarbon materials -- asphalt, pitches and organic resins -- are included in this adhesive category. Very little modification other than blending with various additives is carried out on these materials after initial petrochemical production.

(2) Synthetic Adhesives

- Elastomeric adhesives and cements are manufactured by mastication (milling) of the raw elastomers and blending with solvents and other additives. The most frequently used elastomers are butyl rubber, polyisobutylene, nitrile rubber, SBR and neoprene.

- In-use polymerization of polysulfides forms the basis for some adhesives and sealants. Such products are usually two-part systems which are mixed at the point of application. However, monomers, curing agents, reaction retarders, reinforcing agents and fillers are premixed in one or more of the parts.

- Thermoplastic adhesives are prepolymerized materials that become fluid and are applied upon heating to 175°F and above. They do not require solvents, but rather rely on the melted state for proper viscosity. The manufacture of thermoplastic adhesives consists mostly of polymerization reactions followed by blending with plasticizers, fillers and reinforcing agents. Products are packaged as powders, sheets, cubes and pellets. Included are polyethylene, isobutylene, polyamides and some cellulosics.

- Thermosetting adhesives are essentially reaction type adhesives. These products are most often multipart systems and must be mixed at the point of application. Monomers, curing agents, reaction retarders, reinforcing agents and fillers are premixed in one or more of the parts. Some common thermoset adhesives are epoxies, urethanes, phenol-formaldehyde, polyvinyl butyral, and cyanoacrylates.

- Progress in adhesives development has paralleled progress in polymer development over the past 20 years. As more exotic or stable materials have become available, adhesives capable of functioning in difficult circumstances -- such as in high temperatures or with difficult to bond surfaces -- have been developed. The organo-silicones, s-Triazine and modified phenolics are examples. These adhesives may be solvent-based, thermoplastic or thermosetting, but all require some type of component mixing in manufacture.

Manufacturing and Application Processes

Most adhesives are applied as fluids at their point of use. This ensures full coverage and allows wetting of the surfaces to be bonded. Therefore, in addition to the mixing required for multipart systems, the primary processes in adhesives application are based on spreading adhesives as liquids -- either cold or hot. This is usually followed by drying and possibly compression of the bonded joint. The equipment most often used in the adhesives industry can be described in general terms for manufacturing, but must be related to adhesive types for application.

Manufacturing Equipment

The formulation of most one-part and multipart liquid and powder adhesive systems requires the mixing of resins, curing agents, catalysts, reaction retardants, reinforcing agents, fillers, plasticizers, tackifiers, wetting agents, and water or organic solvents. This is accomplished in open or closed mixing tanks with single or double mixing propellers or blades. Heavy duty mixing tanks, sigma mixers, Banbury mixers, and vertical and horizontal churns are used with high viscosity liquids and elastomers.

Some adhesives require special processing and therefore special equipment prior to final formulation. For example, animal and vegetable glue formulations require the use of grinding and cutting equipment, solvent-degreasing and washing tanks, protein extraction apparatus, filters and dryers. Starches must be milled prior to use in starch-based glues.

Perhaps the largest use of special equipment occurs in the manufacture of those organic adhesives requiring chemical modification of the original raw materials. Reactors must be used in oxidizing or hydrolizing starches, in cross-linking cellulose and soybean materials, and in partially or fully polymerizing resin based thermoplastic and thermosetting adhesives. Many of these reactions can be carried out in

mixing tanks; however, others must be carried out in enclosed, jacketed reactors.

Application Equipment

Adhesives application equipment is best described in terms of both one-part adhesives and multipart adhesives.^(68,73)

One-part adhesives are applied by hand when used in piece-by-piece operations -- as in furniture, automobile, aircraft, plywood and shoe manufacture. The adhesives may be applied by brush, dip, trowel, knife, roller, spray gun or other special applicator. When continuous adhesive application is practical -- as in coating paper, textiles and plastic sheeting -- continuous knife applicators; spray applicators; roll, drum and wheel applicators; extruders and curtain applicators are used. Each of these devices usually is associated with peripheral equipment such as pumps or other feed apparatus, backing rolls or drums, and adhesive reservoirs.

Thermoplastic adhesives, which are applied as hot-melts, require specialized equipment. Either a heated reservoir is used to supply adhesive as a fluid to an applicator or the applicator itself is heated to bring adhesive to its melting point. Once fluidized, hot-melts are applied by heated roller, knife, pressure gun or wheel.⁽⁷⁴⁾

Most emphasis in the proper use of multipart adhesives is placed on mixing of the parts. Because of the limited lifetime of these adhesives, mixing is most often done in batches, either by hand or with laboratory scale mixing equipment. Adhesive application on a piece-by-piece basis makes use of the same manual equipment described under one-part systems. Continuous application requires complex metering, mixing and dispensing equipment. Usually only enough adhesive is mixed as is needed by the dispensing equipment. Such equipment may consist of pumps, sprays or extruders.

The curing of many adhesives is enhanced by forced air and heat. The equipment used for this purpose includes various types of driers and ovens. Batch pressing or continuous roller pressing of bonded materials is often conducted while adhesives are setting up.

Exposures and Controls

The operations involved in the manufacture of synthetic adhesives are identical to those conducted in the plastics and rubber industries to convert resins into finished products. The only differences appear to involve the final form into which the product is prepared. Whereas in the plastics and rubber industries the product may be in the form of a solid object after molding and curing, the adhesive industry supplies solutions or dry powders which can be applied to various surfaces before curing. Since these "masterbatching" operations are

identical, the evaluations for these other industries can be considered adequate in describing the operations and their associated exposure hazards. Indeed, it appears that the plastic and rubber industries themselves include prime examples of companies which manufacture limited quantities of finished adhesive products for outside distribution or captive use.

The manufacture of natural adhesives generally involves some sort of extraction or reaction process followed by filtering, drying, milling, and/or dissolution in solvents. Preparatory steps for animal glues also include grinding and solvent-degreasing. Various aspects of these operations, especially where toxic solvents are used, can be expected to have the potential for resulting in excessive exposures, just as they have been noted to do so in other industries investigated.

Overall, the conclusions can be made that there is considerable potential in the manufacturing operations conducted within this industry for exposures to occur, that these operations are by no means unique to this industry, and that the problems which would occur and the controls appropriate for them are covered elsewhere in this report.

The application of adhesives for the bonding of materials might be conducted in numerous industries ranging from the manufacture of military aircraft to that of wooden furniture. Wherever solvent based glues are used, one can expect that solvent vapors will be evolved. Where adhesives are applied at elevated temperatures, the ILO⁽¹²⁾ reports that there may be "high evolution of fume and vapor."

Knife-over-roll, air knife and kiss roll coating techniques are used for coating paper, fabric or other flexible materials. Spraying may also be used. Houwink and Salomen⁽⁷⁵⁾ report that cooled rollers facilitate the application of adhesives containing solvents that evaporate quickly, "although generally speaking such adhesive solutions are best applied by spraying."

The spray techniques utilized include the well-known air and airless spray techniques and the use of flame spray guns. A feature of these latter devices is that they handle a fusible powder instead of a liquid. The powder is melted as it passes through a flame and is deposited in molten form on the surface of the adherend. An advantage of their use is that the need for a solvent is eliminated. The other spray techniques obviously require the use of solvents to keep the adhesive in a fluid state.

Numerous other types of complex and specialized machinery are used for applying adhesives in paper bag making, book binding, furniture, cabinet and door manufacturing, boat and airplane manufacturing, boot and shoe making, etc. At the other extreme, a variety of simple hand-held glue spreaders, rollers, brushes, and other applicators exist for manual applications.

There appears to be little information in the literature concerning whether occupational exposures to toxic substances result from the application of adhesives. One may infer, however, from comments made in the literature, that the potential is there; again, especially where solvents are used as a vehicle. For example, it is noted that a large weight fraction of solvent-based adhesives may consist of ketones, lower alcohols (including methanol), esters, hydrocarbons, ethers, and other solvents. Concerning urea formaldehyde adhesives, Houwink and Salomen report "the pungent smell of formaldehyde is not only objectionable during the use of the glue, but may persist in the glued material... for months or years." For adhesives containing toluene diisocyanate, they state "the substance is toxic and has a relatively high vapor pressure, making it unpleasant to handle." The possible sensitivity reactions of workers to fumes from epoxy adhesives are, of course, well-appreciated and were reported upon in the evaluation for the plastics industry.

Summary of Operations for Further Study

The operations and equipment concluded to require further investigation in this study are:

- Abrasive-Machining (for removing excess glue)
- Chemical Processes
- Dryer and Curing Oven Use
- Grinding, Crushing and Screening
- Laboratory Operations
- Materials Handling
- Non-Spray Application of Volatile Substances
- Open-Surface Tank Use
- Spray-Finishing
- Textile (and paper) Coating Operations

3.8 DYE AND INK MANUFACTURING

Introduction

Dye sales in 1969 amounted to an estimated \$380 million. About 50% of this could be accounted for by four American-owned firms, 30 to 40% by four foreign-owned companies, and the remaining 10 to 20% by 41 other U. S. - and foreign-owned companies.⁽⁷⁶⁾ Two thirds of these dyes are used in textile processing.

Inks are available for printing on virtually every type of paper, film, foil, paperboard, etc. A 1972 census⁽⁷⁷⁾ of the printing ink industry reported that the industry includes 398 manufacturing establishments (belonging to 200 odd companies), 140 of which have 20 employees or more. The number of production workers at that time was 5,000. The total value of product shipments amounted to \$484 million.

Process Description

Dyes

Beginning with benzene, naphthalene, and anthraquinone, the steps to a dye or pigment through benzenoid intermediate compounds are many and difficult, and essentially involve a series of chemical reactions in typical equipment used in the chemical industry. Because of the exacting nature of dye manufacture, the chemical reactions are run in batches and the processes are labor intensive. According to Stinson⁽⁷⁶⁾ "reactors must be loaded from drums by hand. Solutions with precipitated product are filtered in huge presses. The filter cake is taken from the press by hand and carried to ovens for drying." The reactors referred to are closed-top, agitated tanks with loading hatches, the presses are typical filter presses, and the dryers are usually of the tray type. The filter cake is removed from the plates of the press by shoveling into the dryer trays.

Dye may be sold as dry powder, which the dyer has to disperse himself, or in liquid or paste forms. Liquid dyes are usually water-based. However, considerable efforts are taking place to perfect methods of solvent dyeing textiles. The companies involved feel that solvent dyeing with chlorinated solvents might eventually solve the water pollution effluent problems of the industry. Since solvents could be redistilled after use, aqueous effluents would be eliminated. Low heats of vaporization would cut down fuel costs, though a solvent recovery system would possibly balance off against the cost of alternative waste treatment plants.

Inks

Various sources^(1,12,78,79) agree in their descriptions of how inks are manufactured. The operations and equipment involved are shown to be the same as those utilized in the paint industry. The similarities are so striking, indeed, that no further description appears necessary.

Discussion

The production processes for dyes contain no procedures which are unique. For the purposes of this study, one can consider that the operations which may result in exposures include chemical processing, the weighing out of ingredients to be added to tanks, dumping of ingredients into the tank, the emptying of filters, the use of drying ovens, and the packaging of products into bags, drums, or cans. Also to be included must be laboratory operations required for analyzing samples throughout the production process and cleaning and maintenance operations. Considering the spillage which can take place in the transfer of filter cakes to drying trays and the transport of the trays to the oven, one might expect that a considerable amount of dry powder would be present after any spilled, wet, filter cake dries in the workplace.

The review of the production process for inks indicated that it is essentially identical to that used for making paints. The hazards and control of these operations were described in the industrial evaluation for the paint and coatings industry and do not warrant further discussion here.

Whether any particular health problems currently exist in either industry could not be determined from the available information. That considerable potential exists for them can however be appreciated. Many of the intermediate compounds in dyes are derivatives of benzene, naphthalene, and anthraquinone. Aniline and its compounds are also widely used. Inorganic pigments used include salts or oxides of lead, cadmium, antimony and titanium. Some dyes are suspected as being carcinogenic.⁽¹²⁾ Substances used in inks are also toxic. In another section of this report, it is noted that printing pressmen have been found to have abnormally high incidences of various serious diseases. If it is considered that the use of various inks can lead to serious health problems, then it must also be considered that workers manufacturing these substances might be subjected to similar hazards.

Conclusions and Recommendations

For both of these industries, there appears to be a need for some sort of exploratory study to determine the nature and extent of occupational exposure to recognized hazardous substances, and the nature and extent of any observable health effects that can be associated with occupational environments in the industry. Such a survey would be especially appropriate for the ink industry if the current study of the printing industry verifies that substances in common inks are more hazardous than once believed. Given the commonness of the various manufacturing equipment and procedures utilized, however, there does not appear, at this time, to be any need for engineering control research directed specifically towards these industries.

3.9 SOAP AND DETERGENT MANUFACTURING

Introduction

According to the ILO,⁽¹²⁾ "detergent" is a general term presently applied to all synthetic washing compounds, although it was originally applied only to "soaps" made from natural fats and oils. For the purpose of this investigation, these terms will be utilized in their current context.

The yearly production of detergents for household use currently approaches 5 billion pounds per year. Soap sales have leveled off at a rate of 1 billion pounds per year. Overall, the companies which manufacture these products constitute a multi-billion dollar industry.⁽⁶¹⁾

Soap

Ingredients (61)

Soap is a product of reaction of the combining of a fat or fatty acid with a saponifying alkali. Though more fatty acids are produced synthetically today than by the splitting of natural fats and oils, the soap industry uses fatty acids produced almost exclusively from natural products. The saponifying alkali most often used is sodium hydroxide, but potassium hydroxide is used to some degree because of the greater solubility of resulting products. Metallic soaps may be manufactured from alkaline earth, metal, or heavy-metal salts of fatty acids.

Finished products are not generally 99.4% "pure" soap. Minerals such as soda ash, caustic potash, sodium silicate, sodium bicarbonate and trisodium phosphate are used as builders or fillers. Other additives may include tetrasodium pyrophosphate, sodium tripolyphosphate, carboxymethyl cellulose, and various preservatives, pigments, dyes, perfumes and antioxidants or chelating compounds.

Fatty acid and Glycerine Production (61)

Three methods are currently used in the soap industry for fatty acid production. The high-pressure hydrolysis process, the only continuous technique, is the one most often used. The equipment train consists of various flash, blending, settling, and holding tanks; a hydrolyzer column; heat exchangers; a vacuum still, condensers; and associated pumping and piping systems. An autoclave operating at temperatures ranging from 300 to 450°F and pressures ranging from 75 to 450 psig is used for some batch operations. The simplest method, the Twitchell process, is conducted in unpressurized tanks at 212 to 220°F.

Soap and glycerol are the reaction products of a fat and a hydroxide. The production of commercial and pharmaceutical grades of glycerine is therefore a part of the soap industry. Typical glycerine purification operations involve equipment trains consisting of typical process plant equipment such as tanks, heat exchangers, condensers and evaporators. Centrifuges and filter presses may be used to separate precipitates.

Soap Manufacturing (1,61)

The soap-making processes can be batch or continuous in nature. Batch processes include the kettle or full-boiled process, the semiboiled process, the cold process, the autoclave process, the methyl ester process and the jet saponification process. Continuous processes are proprietary and include the Sharples and Mon Savon processes. Regardless of their specific details, all accomplish the same steps of soap manufacture.

The kettle or full-boiled process is one which follows the historical and traditional methods used since the beginning of the industry. It

simply consists of a number of steps or operations conducted in a single kettle or a series of kettles. The semiboiled process involves mixing and heating of ingredients in a steam-jacketed crutcher. Externally applied heat is not required in the similar cold process. Since reactions between fats and oils are exothermic, mixtures are simply allowed to stand in insulated containers. In the autoclave process, reactants are pumped through externally heated coils and the hot mass is flashed into a vacuum chamber. Jet saponification involves the use of a special steam nozzle or jet through which hot fats and caustic soda solution are proportioned. Emulsions formed drop into conventional kettles where the reaction goes to completion.

The continuous processes mentioned are conducted in closed vessels. The Sharples process utilizes high speed centrifuges and reaction vessels. The Mon Savon process utilizes a high-speed homogenizer for mixing and then discharges the emulsion onto the hot inner walls of a jacketed reaction chamber.

Soap Finishing (1,61)

Finishing of soap involves its processing into liquid, powder, granule, chip, flake or bar form for consumer use. During these operations various additives mentioned above may be blended with the basic soap stock.

Liquid soaps are blended with other materials in tanks and then packaged in standard bottle filling equipment. They are rarely manufactured today except for some very specialized products.

The oldest and most seldom used method for forming bar soaps involves the pouring of a semiliquid paste into molds, the subsequent sawing of the resulting blocks into roughly bar size pieces, and the stamping of these into the final form. "Milling" processes are most commonly used for bar soaps. In one method, the soap is batched in a mixer called a "crutcher," is flowed onto chill rolls, and then flaked off and passed through a dryer. The flakes can be "plodded" (mixed in a screw or tubular type mixer), fed to a roll mill, plodded again, and extruded in a continuous shape for cutting and stamping. The flakes could also be packaged as is or ground into powders. Other methods, though differing in detail, involve the same types of equipment and operations.

Detergents (1,61)

Ingredients

The raw materials used to manufacture active ingredients of anionic detergents, those which by far represent the bulk of such substances produced, include substances to form the hydrophobic portion of the surfactant molecule, those which form the hydrophilic portion, and those used for purposes of neutralization. Among the first type can be

included alkylates made from long straight-chain normal paraffins reacted with benzene, and normal fatty alcohols produced synthetically or from natural fats and oils. The second category includes sulfur trioxide or one of its hydrates, sulfuric acid or oleum. The last group includes sodium hydroxide, sodium bicarbonate, other sodium bases, ammonia, potassium, diethanolamine, and triethanolamine.

The additives incorporated into detergent formulations are numerous and varied in nature. For the sake of brevity, a summary list of them is presented in Table 4.

Surfactant Manufacturing

The processes for sulfonation or sulfation of organic bases to produce the most common detergents are separate and distinct. Various employed are oleum, sulfur trioxide, sulfuric acid or chlorosulfonic acid in liquid or vapor form. The equipment trains utilized to synthesize the active surfactants are all typical of closed system chemical processes and do not warrant further description.

Detergent Product Manufacturing

The only production process for detergent formulations which is not similar to those used in soap production is that of spray-drying. Since the control of spray-dryer emissions is an air-cleaning problem not of interest to this study, no further elaboration appears to be necessary.

Exposures

The operations in soap manufacturing which can be regarded as dust sources in the workplace include: addition of powdered and fine crystalline materials to crutchers, mechanical sawing and cutting of cold frame soap, milling and plodding soap, air drying soap in steam heated dryers, milling, forming, and packaging. These operations and the grinding of soap chips are noted by Danielson⁽⁶¹⁾ as causing internal plant hygiene problems which require control for worker comfort and safety.

The batching and mixing of fine dry ingredients to form slurries for the production of detergent granules can also cause dust problems. Particular problem areas reported by Danielson are scale hoppers, mixers, and crutchers. This author summarizes the problems encountered in detergent product manufacturing by stating "Conveying, mixing, packaging, and other equipment used for granules can cause dust emissions. The granule particles, which are hollow beads, are crushed during mixing and conveying and generate fine dusts. Dusts emitted from screens, mixers, bins, mechanical-conveying equipment, and air-conveying equipment are quite irritating to eyes and nostrils with continuous exposure. Some of the additive materials, such as enzymes, also cause serious health problems."

TABLE 4

Typical Additives Used
In Detergent Production

Compounds	Purpose	Physical Form Used
Sodium tripolyphosphate	Sequestering agent	Powder, prill, or granule
Tetrasodium pyrophosphate	Sequestering agent	Powder, prill, or granule
Nitrilotriacetic acid and its sodium salts	Sequestering agent	Powder
Sodium sulfate	Filler	Powder
Sodium carbonate	Filler	Powder
Amides of various types	Supplementary surfactants	Liquids
Trisodium phosphate	Alkali	Powder
Carboxy methylcellulose	Prevention of dirt redeposition	Powder or granule
Sodium silicate	Corrosion inhibition, others	Water solutions
Various	Optical brighteners	Powder or liquid
Various	Perfume	Liquid
Sodium perborate and magnesium silicate	Bleaches	Powders
Enzymes	Stain removal	Powders
Others	Perservatives Antioxidants Foam-suppressors Scouring cleansers (including finely pulverized silica)	Varies

Houghton in Reference 80 reports that arsenic, in concentrations ranging up to 700 ppm, has been found in detergents. He also discusses the hazards of sodium nitrilotriacetic acid and of enzymes. Of the latter he reports that extreme precautions are needed to protect workers from the inhalation of enzyme dust and that the Soap and Detergent Association has published a detailed list of precautions to be taken.

The ILO⁽¹²⁾ notes "although the production of detergents and cleaners is largely automated, diseases of the respiratory system may occasionally occur if dust control in the working area is not provided for." It also reiterates the problems associated with the handling of enzymes. Other than occasional skin allergies and dermatitis which may arise from manual handling of chemicals, no health problems are noted for soap manufacturing.

Kirk-Othmer⁽¹⁾, however, reporting on soap manufacturing, states that high dust concentrations may result from some flake and powder processing operations. The dust is noted as being irritating to the mucous surfaces of the nasal passages and throat but not as being particularly injurious. A method for dedusting flakes and powders is described which involves dropping them through a tower against a rising forced current of air.

Discussion and Conclusions

There is not a great deal of information available on the health problems of this industry. That which there is indicates that dust may be generated from a variety of operations and that this dust is simply irritating and not "particularly injurious." The majority of operations which appear to represent the problem areas are very common ones involving batching, mixing, materials handling, grinding, milling, and packaging. Dusts containing enzymes are noted to be a significant problem which presumably has been solved by the special handling procedures formulated by the industry.

3.10 PERFUME MANUFACTURING

Introduction

A perfume can be defined as a mixture of substances which are incorporated into a vehicle to produce a pleasing olfactory sensation. Originally, perfumes were only produced from naturally occurring botanical or animal products. Recently, however, the tendency has been to market substances which have no counterpart in nature. These perfumes are made from synthetic materials produced by a variety of chemical processes. The perfumes considered the finest are blends of natural products and synthetic materials. The synthetic substance serves to enhance the odor of the natural perfume, reduce the market price of the formulation, and produce an entirely unique fragrance.

Ingredients (1,12,69,81)

Vehicle/Solvent

A somewhat volatile solvent helps project the odor of a perfume away from its carrier. The most widely used vehicle in the industry is ethyl alcohol in various dilutions. Ethyl alcohol is fairly inert to the solutes and is relatively non-irritating to the skin.

Fixative

Fixatives are substances which have a lower volatility than that of perfume oil. Their purpose in a formulation is to retard and even up the rate of evaporation of various odorous constituents. Fixatives may or may not add to the odor of the product. Some main categories of fixatives are animal secretions, essential oils, resinous products and synthetic chemicals. The latter are usually odorless esters used to substitute from some imported animal fixatives.

Odorous Substances

The odorous substances used in "perfumery" can mostly be represented as essential oils, isolates, and synthetic or semisynthetic chemicals. The essential oils are of vegetable origin and can consist of mixtures of compounds representing most types of chemical structures (i.e., various esters, alcohols, aldehydes, acids, phenols, ketones, lactones, terpenes, and hydrocarbons). An isolate is a pure chemical compound, which as its name suggests, is isolated from some essential oil or other natural perfume material. Synthetics are obviously manufactured by chemical synthesis. Semisynthetics is a term utilized to describe constituents chemically synthesized from an isolate or other natural starting material. Included in these latter categories are such substances as vanillin, ionone, terpineols, coumarin, diphenyl oxide or ether, cinnamic aldehyde, benzyl benzoate, phenylethyl alcohol, benzaldehyde, and others.

Manufacturing Processes

Synthetic Constituents

Acetylene and aromatic coal tar constituents are usually the starting materials for the synthesis of perfumes and essences. The manufacturing processes and equipment used are typical of those used throughout the chemical industry and can be considered to be closed-system chemical processes.

Natural Constituents

Naturally occurring compounds are processed by steam distillation, expression, fat or solvent extraction, exudation, dry distillation, and even by ultrasonic treatment. The first three of these are of most interest.

Steam distillation is commonly conducted in stills of about 600 gallon capacity. The material to be subjected to the steam is first ground, chipped, or cut into small pieces before charging to the still. Although distillation is most often conducted at atmospheric pressure, the process may be run in a vacuum if the constituents of the oil are easily subject to hydrolysis. The steam is collected with condensers, and separators are used for dividing the resulting oily layer from the aqueous one. The crude oils retrieved may be further processed before use by a variety of physical or chemical treatments.

Expression involves machine pressing operations to squeeze out oils present in fruit. The enfleurage process is a cold-fat extraction process for some flowers. The fat usually consists of a mixture of tallow, lard, and a preservative. Once the fat has been exposed to a sufficient quantity of flowers, it in turn is subjected to extraction with an alcohol.

The most successful solvents for solvent extraction processing are petroleum ether and benzene. Others used include acetone, toluene, dichloromethane, and ethyl alcohol. Extraction equipment consists of stills for fractionating the solvent, batteries of extractors, holding tanks for solvents and solutions, and an evaporator. Two types of extractors are employed; the rotary drum type and the stationary vertical cylinder type. Use of either type of extractor involves the charging of the flowers or other materials, repeated washing with the solvent, and solvent recovery from the residue with either steam or vacuum.

Exposures

The ILO⁽¹²⁾ simply recommends that where toxic solvents or other toxic substances are used (e.g. benzene, acetone, toluene, dichloromethane, etc.), their concentrations in equipment and in the workplace air should be maintained at levels which do not present explosion or health hazards. Addressing the toxicity of the ethereal oils, it reports that the results of research into the toxicity of these substances "indicates that little precise information is available on the toxicity of the main components and that nothing at all is known of the toxicity of the minor components or oxidation products." It further states that "the continuing use of perfumes and essences in food or for external application should provide sufficient reason for systematic studies on the pharmacology and chronic toxicity of all components to ensure that these substances do not contain certain harmful or even carcinogenic constituents."

Addressing the hazards of perfumes in general, Sax⁽⁸²⁾ lists them as being acute and chronic allergens of slight toxic hazard. The acute and chronic effects by inhalation are similarly rated while the acute systemic effects of ingestion are rated as being of moderate toxic hazard.

Other information concerning the health hazards of the industry was not found.

Discussion and Conclusions

From the descriptions of the various equipment used and operations conducted in the perfume industry, it appears that those in any way unique to the industry (i.e. expression, fat extraction, etc.) are not of a nature to result in exposures to known toxic substances. Whether they result in exposures to substances which are of yet unrecognized toxicity is another matter.

The other operations conducted appear to include those which are quite common to many industries and which have already been listed as such in preceding industry evaluations.

3.11 PRINTING

Introduction

The printing industry today is very complex, involving processes and operations ranging from art-and-copy preparation to presswork, binding and other finishing operations.

The products of the printing industry are ever-increasing in complexity, variety, and quantity. The ILO⁽¹²⁾ points out that, in America, "printing is the third most important industry in the production of non-durable goods, preceded only by food and clothing," and that about 4% of the total work force of all manufacturing industries is involved in the printing industry. It also notes that "between 50% and 70% of all printing establishments employ fewer than 25 people."

There is recent evidence to indicate that respiratory diseases can be caused by agents in the workers' environment in printing plants. An investigation of members of the Printing Pressmen's Union has shown that their mortality rate from emphysema is much greater than the national average.⁽⁸³⁾ Thus, not only is this industry representative of one which utilizes a large number and variety of toxic agents, but one in which serious worker health problems currently exist.

In the following, we generally describe the basic processes and equipment used in the printing industry, the health hazards associated with these operations, and the controls which have been implemented.

Processes and Equipment

There are three basic methods of printing: letterpress, lithography, and gravure.

Letterpress

Marsailles⁽⁸⁴⁾ explains that letterpress printing involves the application of ink to a raised or relief surface by ink rollers, and then transfer of an image by applying the surface, under pressure, to paper. Strauss⁽⁷⁸⁾ notes that letterpress printing is actually only one

of four basic relief printing methods. The others are: newspaper relief printing, flexographic printing, and indirect relief printing. These methods differ widely in their products, printing inks, stocks, and presses.

The ILO points out that in small businesses most or all of the letterpress operations and processes are performed in one work area, whereas in the larger firms, the individual operations (i.e. composing, stereotyping, binding) are carried out in separate work areas.

Composing can be done either manually or automatically. When the composing is done by hand, the compositor holds a composing stick in one hand, picks up the type with the other hand, puts the type in the stick, and then spaces the words so they fit the line properly. For the setting of large quantities of type, a machine operator uses a keyboard (like a typewriter keyboard) to tap out copy. Linotype and Intertype machines are usually used for casting solid lines of type, whereas Monotype machines are used for casting lines of individual characters. Molten metal is used to cast the type.

After the type has been cast and placed in shallow metal trays, it is proofed and corrected as necessary. The material is then assembled into units, each representing a page. "Imposition" is the process of assembling pages for presswork so that once the printing is finished and the pages are trimmed and folded, the pages will be in the right order.

Duplicate plates are usually made to increase the speed of the printing process and prevent the original type or blocks from becoming damaged. Strauss points out that type forms cannot be curved, and therefore are not useful for the rotary presses, the fastest type of letterpress. Since duplicate plates can be either flat or curved, they can be suitable for rotary presses. There are four principal types of duplicate plates: stereotypes, electrotypes, rubber plates, and plastic plates.

Stereotyping and electrotyping are the two main duplicating processes by which plates are made. These operations may be performed in the foundry section of a printing firm, but usually are contracted out. In stereotyping, a mold is used to cast the molten metal, though rubber or plastic "stereos" are often used in rotary presses. In electrotyping, a thin layer of copper or nickel is plated out on a mold of wax, lead, or plastic which has been made from the original form.

After the type, block or duplicates have been prepared, the form goes to press. According to Strauss, there are three general categories of presses for letterpress printing: platen presses, flatbed cylinder presses, and rotary presses. Rotary presses are usually used for high-speed mass production printing, whereas platen and flatbed cylinder presses are used for short and medium-length runs.

Platen presses are the smallest and simplest of the letterpress presses and are often found in small printing firms. They may be sheetfed

by hand ("open presses"), by machine ("job automatics"), or roll-fed (webfed). The ILO points out that a platen machine "puts the whole of the printing surface under pressure in one operation."

Flatbed cylinder presses can print directly from type or duplicates. These presses can print larger areas than platen presses without requiring as much impression power. Instead of printing the whole area at one time as the platen presses do, they make impressions in small segments. There are three kinds of flatbed cylinder presses: single-color presses, two-color presses, and perfecting presses.

The third kind of press for letterpress printing is the rotary press. As noted, the main benefit of rotary presses is that they are more efficient than the others, and therefore more useful in mass production printing. Rotary letterpresses can either be roll-fed or sheetfed and incorporate either of two basic construction principles. For printing one side of paper, sheetfed presses are usually used, whereas for printing both sides of the sheet or web, roll-fed presses are used.

Lithography

In lithography, certain areas of a flat surface are chemically treated to be "ink-receptive" and other areas are treated to be "water-receptive" (or "ink-repellent"). The "ink-receptive" areas become the printing areas, and the "ink-repellent" areas become the non-printing areas. (78)

In the early days of printing the image to be printed was drawn in greasy, ink-receptive chalk on a porous stone and the remainder of the stone was wetted. (12) Next, a greasy-ink which only adhered to the greasy chalk was rolled over the stone. The ink was transferred to the paper by rolling a cylinder covered with paper over the treated surface. In later times zinc, aluminum, or stainless steel plates were substituted for the stone. Since the aluminum and zinc plates could be curved, rotary lithography presses came into being.

Platemaking is the last step in converting original images into image carriers for lithographic printing. There are four main stages in lithographic platemaking: (1) selection and preparation of the base metal for the plate, (2) photomechanics for lithographic platemaking, (3) formation and protection of image areas, and (4) formation and protection of non-image areas.

To prepare plates for coating, the plates must be "grained" and "counter-etched." Through graining, old plates can be prepared for reuse. There are several methods of graining. In one method, the plate is put in a "tub graining" machine which contains metal balls ("marbles") and an abrasive water mixture. In "brush graining" electrically rotated brushes prepare the surface for coating. Once the plate-surface has been grained, it is counter-etched if it is rough.

In addition, the plate surface is pretreated (cleaned and deoxidized) so that the coating necessary for the photomechanical image formation can adhere properly to its surface⁽⁷⁸⁾. Once coated and exposed, the light-sensitive coating is developed and a photomechanical stencil is made.

In order to form and protect the printing image, plates are treated with various chemicals and lacquers, the choice of which depends upon the type of plate being prepared (i.e. surface or deep-etch plates). The purpose of this step is to ensure maximum adhesion of the image to the image carrier, to provide a high degree of water repellency, and to provide a surface which is not easily damaged.⁽⁷⁸⁾ The non-image areas are also treated with various chemicals to provide an extremely water-receptive surface to which ink cannot adhere. After proofing, the plates are then ready for the press.

In offset lithography, the ink is first transferred to a rubber blanket, and then from the blanket to the paper. Newer presses based on the offset rotary principle operate at high speeds and can be either sheetfed or web-fed.

Gravure (12)

Gravure printing (intaglio) utilizes printing-image carriers in which the printing areas are sunken below non-printing areas. Preparation of gravure plates or cylinders for the press first involves the exposure of a screen and then a positive onto a carbon tissue (a layer of light-sensitive gelatine attached to a sheet of paper). After fixing this to the cylinder and developing with warm water, an etching solution is applied in stages to the surface. The etching process can be performed manually, but automatic etching machines and electronic engraving machines are available.

In the fast-operating rotary gravure presses, a very volatile, solvent-based ink is used. This type of ink allows rapid refilling of the depressions in the cylinder and evaporates rapidly. Since the evaporation rate is significant, exhaust hoods are often present over these presses to minimize fire, safety, and health risks caused by solvent vapors. Special drying units are sometimes used to dry the deposited ink.

Photogravure is a special form of intaglio printing. Here, the design is etched into a copper-coated cylinder or a copper-plate. An ink of low viscosity is applied to the surface of the gravure cylinder or plate, and a "doctor blade" scrapes the surface to force ink into image areas and remove it from non-image areas. When the paper and the plate or cylinder meet, the ink leaves the recesses and transfers to the paper. Since this is a rotary method, it is also suited for mass-production printing.

Binding and Finishing

Additional work is usually necessary to finish the product after the paper has come off the press. Some printers enlist the services of private businesses for such work, but others have their own departments for these processes. Most printers, however, have at least a "power-cutter" or some other binding and finishing machine.

According to Strauss, there are nine main stages of binding: "(1) planning for printing to be bound, (2) cutting of sheets, (3) folding of the printed sheets, (4) assembling of the folded material for binding, (5) binding proper, or fastening the assembled material in book form, (6) trimming, (7) preparing the book for covering, (8) cover-making, and finally (9) combining of cover and bound book. The ILO points out that automatic and semi-automatic machinery can be used to perform most of these operations.

Health Hazards

Fairley⁽⁸⁵⁾ reports there are numerous hazardous chemicals used in the printing industry but that "in most cases the risks from these substances are adequately controlled by ventilation, proper handling precautions, etc., or are comparatively slight, and most workers have little need to worry about their health during their working lifetime. Where harm may result, however, is from accidental breakage, spillage, leaks, from carelessness, undue sensitivity or perhaps because the dangers are unrecognized or unknown. The main health or safety hazards from these causes with which the printer is likely to be concerned are the dangers to the eyes and the skin, through ingestion and inhalation, or from the risk of fires and explosions."

Fairley⁽⁸⁶⁾ states that there have been no reportable cases of lead poisoning in the printing industry in England during recent years. He notes, however, that when lead poisoning does occur, it occurs through inhaling dusts or fumes of lead, not through the handling of type metal. Sources of lead fumes and dusts are listed as:

COMPOSING DEPARTMENT

- Dust in type cases, not from handling type or type metal.
- Wire brushing of metal pot plungers.
- Metal dust from matrices after casting slugs.
- Drossing of metal pots.
- Careless dumping of dross on floor.
- Sweeping up and bagging of dross.

STEREO AND FOUNDRY DEPARTMENTS

- Drossing of metal.
- Careless dumping of dross on floor.
- Sweeping up and bagging of dross.

The author adds that since "the temperature of metal pits in printing shops is not high enough to give off lead vapors during type founding,... caster attendants, lino operators and stereotypes are not formally in any danger... Great care should be taken in the skimming of metal pots and in the handling of dross. The remelting and drossing of metal should not be carried out by unskilled workers who have no knowledge of the dangers involved." Also stated is that dust in type cases does not contain much lead but, nevertheless, should never be removed by blowing out.

Bronze powders have presented a significant exposure hazard in the past, since lead used to be (but is no longer) one of their main constituents. Now, however, the only hazard of bronze powders is from inhalation of the dust.⁽⁸⁶⁾ Solvents used in the printing industry in inks and for cleaning type and presses can obviously present health hazards. "There is a weak anaesthetic action from solvent vapours which may cause deterioration of health if breathed continuously over a period." ⁽⁸⁷⁾

Finally, it has been discovered that there is an alarmingly high prevalence of respiratory impairment among members of the International Printing Pressmen and Assistants' Union of North America (IPP & AU). Dr. Ruben Merliss of Los Angeles found that 90% of the web pressmen working in the L.A. Herald-Examiner pressroom have "lung problems ranging from lung cancer, emphysema, bronchitis to pneumonia. In testing inks he found possible cancer caustive factors in mineral oil and lampblack... both are used in ink formulas."⁽⁸⁸⁾ In addition, such toxic substances as "chrome and methyl mercury in color inks, and talc and asbestos in paper dust" have been found in pressroom air.⁽⁸⁹⁾

A research group headed by Dr. Irving Selikoff at the Mount Sinai School of Medicine in New York City has undertaken an in-depth study of the respiratory diseases among printing pressmen, documenting "the degree to which members working at the trade have respiratory problems. Further study of causes and corrective measures will follow if, as expected, the research team substantiates the information developed in the preliminary investigation."⁽⁹⁰⁾

Controls

Concerning controls in the printing industry, Fairley⁽⁸⁵⁾ states that "if chemicals cannot be eliminated or substituted for others in the process, then the necessity for physical contact with liquids, dusts, or fumes should be reduced or removed. Here, the best method of protection lies in total enclosure or complete mechanization of the process, wherever possible. To this end, the printing and the graphic reproduction industries now have available to them equipment for the automatic processing of films and plates. Automatic etching of rotogravure cylinders is also possible and this means that instead of the etching room being the messiest part of the plant it is the cleanest... Reduction of contact may also be achieved through the use of mechanical aids such as tongs, trays, dispenses, etc., or by the

use of splash guards and screens. Local exhaust ventilation is also an important factor where dust or fumes are involved. Hooded exhaust systems are seen in many factories to overcome this problem and probably need no comment. Fume extraction tables, which provide a complete safeguard both for the health of the operator from toxic etch fumes and against corrosion of nearby equipment, are also available from a number of suppliers."

Marsailles⁽⁸⁴⁾ points out that "the nature of the various printing processes necessitates special considerations in the design of air management systems of printing plants. For example: drying time of inks dictates allowable humidity tolerances, as does incidence of static electricity; evacuation of particulate and chemical pollutants is a special need; some presses operate at high temperatures, affecting ventilation system design; drafts can cause misalignment of paper entering the presses; and while accounting for the special needs of the machinery, human comfort cannot be neglected."

Greiner⁽⁹¹⁾ discusses different techniques for attempting to achieve dust free cutting. He indicates that the increasing use of offset printing for long, high speed runs has intensified the concern for dust control in the printing industry since valuable time is lost if a printer has to shut down presses to clean off press blankets which have accumulated dust. He describes methods of cutting which do not produce dust, and suggests that these methods may be more economical for the control of dust rather than removing dust once it has been produced.

Gadomski et al⁽⁹²⁾ report data from several controlled and uncontrolled metal decorating processes. In defining this type of operation, they state that "metal decorating can best be described as the application of ink (printing process) and various types of coatings (coating operation) to a flat sheet rock or metal plate. The standard printing process utilized is sheet-fed (offset) lithography." The lithographic inks for metal decorators consist of alkyd resins, solvents (approximately 15%), and various sizings and coatings. Generally, coating materials consist of vinyls, acrylics, alkyds, and oleoresinous or phenolic lacquers. After the resinous material (and then perhaps a pigmented material) is applied to the metal, a coating of varnish is usually applied by a varnishing unit before the metal sheets go into the baking oven. In the oven, low velocity heated air is passed over the sheets to dry the metal. An exhaust outlet vents the solvent vapors from the oven to the atmosphere. The authors point out that "further studies are definitely needed to determine the actual extent that an oven's operational structural, and mechanical characteristics can affect the level of pollution ultimately emitted from the oven."

In describing the processes and controls for letterpress printing, Marsailles states that, since sheet-fed printing is a slow operation, the ink is virtually dry once the sheets come off the press. In order to prevent "offsetting or the transference of an image from one sheet

to another," each sheet is usually dusted with a powder or a starch after printing to hold them apart until they dry properly. It is pointed out that, since the dispersed starch particles are large (30-40 μ) and tend to settle out on surfaces, they present a house-keeping problem. Apparently "an effort has been made to provide hoods to capture starch particles but results were inconclusive. An adequate capture velocity tends to pick up starch off paper sheets defeating the prime purpose of the starch." In order to eliminate the housekeeping problems, the possibility of substituting the starch with a silicon fluid of low toxicity has been considered.

Marsailles also discusses the ventilation of the driers for printing. He states that the driers for weboffset printing and for webfed letterpress are the same type. For weboffset lithography, however, drying is not as major a concern, since not as much ink is applied and the presses do not operate at as high speeds.

Both weboffset printing and web letterpress printing involve the use of heatset inks. These inks "dry on the printed surface by evaporation of organic solvents under the influence of heat and air current. Drying is achieved through either a direct flame hot air (d.f.h.a.) or high velocity hot air (h.v.h.a.) dryer. In the former, the web passes between burners in which flame impinges on the sheet surface and a series of air blasts are blown against the web to remove volatile gases and to help carry off solvents. In the latter type, preheated high velocity air impinges on the sheet surface to drive off solvents." In either method of drying, the atmosphere becomes contaminated with evaporated solvents. (93)

Marsailles mentions two other letterpress (and presumably offset lithography) driers: open flame gas cup and steam drums. The exhaust volumes required are noted to vary according to the type of drier used and the press speed, but in general to range between 7000 and 15,000 scfm, with exhaust temperatures ranging from 250 to 400°F.

Marsailles states that, in rotogravure, ink dries by the evaporation of solvent, leaving a "solid film of pigment (clay), and resin." The author points out that there are separate driers for each individual printing unit, and the airflow through each drier is approximately 4000-6000 scfm. "Exhaust of from 1000 to 1500 scfm is provided at the floor between each unit to prevent any concentrations from accumulating. This is primarily protection against any spillage which may accidentally occur."

Concerning the ventilation for platemaking processes, this author states that most operations have lateral or downdraft exhaust systems. Since the plates are usually lowered into the tanks from above for plating, etching, or other operations, the ductwork must be below or to the side of tank, thus making lateral exhaust the most commonly used ventilation technique for open surface tanks. He points out that "exhaust quantities could vary somewhat depending upon the nature of the solution

but generally 100 scfm/sq ft of surface of solution is provided and/or a control velocity of 50 fpm at the side of the tank opposite the exhaust intake. It is highly desirable (1) to provide tank covers if possible; and (2) to provide rear and side walls for tanks. Air quantities may then be minimized and/or a more efficient exhaust system may be obtained. Cross ventilation across open tanks which may be caused by drafts of supply air distribution should be avoided."

Marsailles also addresses the need for make-up air in printing establishments. He points out that it is difficult to distribute air properly and suggests that the main duct trunks in production areas be installed adjacent and parallel to the equipment and that, at frequent intervals, ductwork be installed which extends down to about 10 ft from the floor.

Discussions and Conclusions

As clearly shown, there are numerous processes and operations in the printing industry which can result in industrial hygiene and occupational health problems. Some of the exposure hazards are specific to the printing industry, and others are common to many industries.

As is true for the rubber industry, a full-scale effort has been underway for the printing industry to investigate the specific health hazards associated with this industry. NIOSH should not repeat the research which has been and is currently being conducted, but should obtain information concerning the results and activities of this study. Subsequently, it is recommended that NIOSH support research to investigate any specific problem areas identified which would appear to benefit from engineering control research.

4. EVALUATION OF COMMON OPERATIONS

4.1 INTRODUCTION

This section of the report contains the results of investigations conducted to determine the availability and adequacy of engineering controls for those operations categories which are common to a number of industries. Included are all such categories found in Table 3 and those which were identified from the industry evaluations in Section 3 of this report.

4.2 ABRASIVE MACHINING OPERATIONS

Introduction

The term "abrasive machining operations" is used here to include all operations involving the shaping or surfacing of solid workpiece materials using abrasive machine tools. The operations include grinding, polishing, sanding, abrasive sawing, and buffing, but do not include abrasive blasting.

An abrasive machining operation is characterized by the removal of material from a workpiece by the cutting action of abrasive particles contained in or on a machine tool. The workpiece material is removed in the form of small particles and, whenever the operation is performed dry, these particles are projected into the air in the vicinity of the operation. Ventilation in its various forms is used routinely with abrasive machining operations to control employee exposures to airborne particulates generated by the operations.

Existing Ventilation Criteria

Current recommended practice in the application of ventilation methods to various types of abrasive machining operations is summarized in the ACGIH Industrial Ventilation Manual.⁽¹¹⁾ Ventilation methods are described which have been found through industrial practice to be effective in controlling exposures of workers to airborne dusts generated by the operations. The methods described in the Industrial Ventilation Manual are recommended primarily for control of inert dusts resulting from machining non-toxic workpiece materials with abrasive tools. The methods include open and enclosing hoods as applied to metal and woodworking operations.

A second source of ventilation criteria for abrasive machining operations is a report on a NIOSH-sponsored investigation of ventilation requirements for grinding, buffing, and polishing of metals.⁽⁹⁴⁾ In this investigation, quantitative criteria were developed which relate breathing zone dust concentrations to machine and ventilation system parameters. These criteria allow the results of the investigation to be extrapolated (with caution) to machine sizes and speeds outside the ranges investigated and to the control of moderately toxic contaminant materials. This investigation was directed primarily toward the performance of open and shaped exhaust hoods.

A third source of ventilation criteria is a report on experience with the control of beryllium dust.⁽⁹⁵⁾ In this report, methods of controlling beryllium exposures from grinding operations are described. The methods are based on the use of ventilated enclosures.

Many other publications are available which generally describe ventilation methods applicable to machining operations. A bibliography of such publications is contained in Reference 94. However, these publications do not provide sufficient information to guide an operator in the selection and operation of ventilation equipment.

Identification of Problem Areas

Problem areas in the ventilation of abrasive machining processes can be identified best by means of a matrix defining combinations of ventilation methods and contaminant materials. The matrix, shown in Table 5, defines 12 material-method combinations or problem areas. The matrix could be extended in a third dimension to include different classes of abrasive machining equipment. However, this added degree of complexity is not necessary for a discussion of research requirements. In the matrix, the problem areas are identified for which ventilation criteria exist. The spaces in the matrix without entries represent problem areas for which ventilation method performance data and design criteria are not available or do not exist. However, not all of the open spaces represent problems of equal significance. For example, the use of enclosures for the control of inert materials is not common except for complex machines such as automatic buffing equipment. In the next section, the problem areas requiring investigation are discussed in an order which represents the priorities attached to the data requirements.

Discussion of Problem Areas

Non-Metals/Open and Shaped Hoops

Abrasive operations are widely used in the woodworking industry and in manufacturing many types of building materials. To a lesser extent, abrasive operations are used in the manufacture of ceramics, masonry materials, stone, glass, asbestos products, and other non-metal products. Most contaminant materials generated by these operations are inert. However, asbestos and silica are encountered in some operations.

Very few data are available on the contaminant exposures associated with abrasive machining of non-metals or on the performance of ventilation methods used to control these contaminants. Detailed guidelines for ventilation system design and operation are available only for woodworking operations,⁽¹¹⁾ and ventilation criteria for abrasive machining of metals may not be applicable because of differences in contaminant generation rates. Consequently, it is

TABLE 5

Matrix of Problem Areas in Ventilation of
Abrasive Machining Operations

Materials →	Inert		Toxic	
	Metals	Non-Metals	Metals	Non-Metals
↓ Methods				
Open and Shaped Hoods	(Refs. 11 & 94)*	(Ref. 11 - Wood)	(Ref. 94)	
LVHV Hoods				
Enclosures	(Ref. 11)		(Ref. 95)	

* Notes refer to sources of ventilation method performance data.

not possible with existing data to assess the significance of the problem of employee exposure to contaminants from abrasive machining of non-metals, nor is it possible to define ventilation requirements wherever such problems are observed.

To assess the significance of this problem and to provide a basis for ventilation guidelines, it is recommended that a program be initiated similar to the previous program sponsored by NIOSH on ventilation requirements for grinding, buffing, and polishing operations.⁽⁹⁴⁾ This new program, however, should be directed toward the control of non-metal contaminants from abrasive machining operations commonly used with non-metals. The program should have three objectives: (1) to identify operations involving abrasive machining of non-metals, (2) to compile a data base on the performance of ventilation methods used with these operations, and (3) to develop ventilation criteria for these operations. The program should consist of three corresponding tasks.

The first task should consist of a survey of abrasive machining operations used with non-metals and should provide a classification of these operations and the contaminant materials which they generate. In this task, persons or organizations should be used who are familiar with these operations.

The second task should include field measurements of worker exposures with various classes of operations and contaminant materials. These measurements should be conducted as far as possible under actual industrial operating conditions.

The third task should involve the development of ventilation guidelines for the various classes of operations based on the exposure data compiled in the second task. The ventilation performance models described in Reference 94 can be used in the development of these guidelines.

Metals and Non-Metals/Low-Volume-High-Velocity Hoods

The low-volume-high-velocity (LVHV) hood is a relatively new approach to exhaust hood design. The approach appears to be a simple extension of the use of open hoods; however, the operating principle of LVHV hoods is different from that of open hoods. The LVHV hood is designed and operated to control air contaminants at the point at which they are generated by inducing exhaust velocities at the generation point higher than the release velocity of the contaminants. With this design approach, the contaminants are not allowed to travel beyond the generation point and, hence, a small hood is sufficient to achieve a high capture efficiency with attendant savings in energy and equipment requirements.

At the present time, there are no data in the public domain on the performance of LVHV hoods, and guides to their use are non-specific.⁽¹¹⁾ Consequently, the design and application of these hoods are trial-and-

error processes. It is recommended that a program be initiated to investigate the performance characteristics of LVHV hoods used for the control of contaminants from abrasive machining processes.

The LVHV hood program should have three objectives and consist of three tasks analogous to those recommended for the previous program. These objectives and tasks should be directed toward (1) classification of operations and contaminants, (2) compilation of ventilation performance data, and (3) development of ventilation system design and performance criteria.

The classification task should identify operations with which LVHV hoods are used currently, as well as other operations which are potential applications of LVHV hoods. In this task, the experience of manufacturers of LVHV hoods should be utilized as far as possible.

The data compilation task will require a laboratory test program because of the limited use of LVHV hoods in industry at the present time. A laboratory program will be necessary in order to provide all of the hood applications which should be investigated.

The criteria development task will require formulation of ventilation performance models specific to LVHV hoods. These models can then be used to correlate the data compiled in the previous task.

Metals and Non-Metals/Enclosures

Enclosures are most often used for control of highly toxic contaminants or for controlling contaminants from complex machinery. The operational criterion for an enclosure generally is a simple prescription of a minimum face velocity.

Collection of performance data on enclosures is not regarded as a high-priority requirement. However, additional data on enclosure performance would provide a firmer base for the development of guidelines for the design and operation of enclosures used with abrasive machine operations. Such a data base would be most useful for operations involving toxic materials.

It is recommended that a program be considered wherein enclosure performance data would be collected from existing facilities. These data would be collected as a part of a simple field measurement program which might also include investigations of ventilation method performance for other industrial operation categories.

Summary of Program Recommendations

Three programs have been recommended for the development of ventilation criteria for abrasive machining operations. Suggested durations and levels of effort for these programs are listed below.

<u>Program</u>	<u>Duration</u>	<u>Effort</u>
Non-Metals/Open Hoods	12 months	2-3 Man-years
LVHV Hoods	12 months	2-3 Man-years
Enclosures	9 months	1-2 Man-years

4.3 CHEMICAL PROCESSES

Introduction

The processes and operations which can be termed as "chemical processes" are numerous and varied in nature. It is therefore not surprising that such a high percentage of the toxic substances with which we are concerned have been described in the literature as being utilized in chemical processes.

According to ILO⁽¹²⁾, such processes in the chemical industry involve "chemical or physical changes in the nature of substances and particularly in the chemical structure and composition of the substances. This covers a much wider field than just 'chemicals' since it also includes such principal products as fertilizers, dyestuffs, pharmaceuticals and medicinal products, explosives, plastics, resins, adhesives, cosmetics, synthetic rubber, photographic films, synthetic and artificial fibres, detergents, soap, paints, as well as the multiplicity of inorganic and organic substances which can be classified as 'miscellaneous' chemicals."

The ILO describes "chemical processes" as including "crushing, grinding, size separation, filtration, drying, heating, cooling, solvent extraction, absorption, distillation, fractionation, electrolysis, mixing, blending, analysis and process control, packaging and transport." As is evident, this list comprises most of the operations utilized in any of the manufacturing industries, and in some service industries. Indeed, it covers many of the more specific categories of use/exposure's which will be treated individually and in detail in this report. For this reason, we will here only consider those equipment types which are usually specific to the actual manufacture of chemical feedstocks, i.e. the "raw" materials from which industry manufactures the products which we utilize in our everyday lives. If in making this differentiation we realize that we have excluded materials handling and grinding, crushing, and screening equipment for solids, it becomes evident that we are primarily left with equipment or overall process systems which cause the contacting, reaction, or separation of gases and/or liquids. If we additionally impose the condition that chemical process companies involved with the manufacture of large volumes of chemicals utilize "closed" systems, i.e. where the chemicals are not blatantly open to the atmosphere, we can safely theorize from an engineering, economic, and practical viewpoint that the exposures to toxic substances in chemical process plants are primarily due to:

1. Releases (i.e. leaks) from joints, closures, etc. in system components normally and functionally considered to be a part of a "closed system" (i.e. fugitive emissions),
2. Intentional releases of contaminants from system component vents,
3. Stack gases from combustion processes, and,
4. Accidental or unintentional releases due to equipment malfunction or failure.

Literature Review

Ludwig⁽⁹⁶⁾, is a paper discussing exposures in chemical process plants, indicates that the specific equipment and practices which must be given "considerably more attention" include valves; conservation, tank and process vents; and relief valves and disks. He makes the point that "many ordinary valves leak continuously even when supposedly shut" and that such leaks "can build up the exposure level to the limits set for air contaminants by OSHA." Concerning the practices of routinely releasing purges, minor overpressures and system breathing to the atmosphere (i.e. heretofore common venting practices), he notes that the contaminants should be subjected to recycle collection, scrubbing, reaction, or other measures to produce safe products or to eliminate their release completely. In doing so, he correctly points out that even if excessive employee exposures are not a problem, EPA emission requirements may still mandate such measures.

Another source of contaminant release discussed by Ludwig and mentioned above is the operation of safety and relief valves. It is noted that specifications for bubble-tight seating and reseating of valves "are receiving considerable attention," that the composition and temperature of some gas streams can make some soft seat materials unacceptable, and that the hard-seat design has been improved to cope with the ever-increasing range of vapor compositions.

The prevention of releases of large volumes of contaminants into the environment from activated relief valves requires that ventings be somehow collected. Ludwig reports an increase in efforts to collect such ventings into headers, and to control fume releases by means of smokeless flare systems. He indicates that this is not a simple task because a header connecting a number of system components must be designed to handle a wide variety of operating conditions, including the possibility of simultaneous release of several streams.

Concerning rupture disks it is stated that they are capable of ensuring bubble-tightness until they relieve. An interesting application is illustrated in which a rupture disk is positioned in a line preceding a relief valve to protect the valve until an overpressure situation becomes imminent.

Wiley⁽⁹⁷⁾ supports the statement that venting practices contribute to contaminant concentrations by noting "vapor losses from tank vents and process vents, and during chemical loading operations, are the primary sources of hydrocarbon emissions in the chemical process industries." His paper then summarizes and discusses the various techniques available for the collection, and recovery or disposal of the displaced vapors.

Discussing compression packings for pumps, Rothman⁽⁹⁸⁾ reports fibrous packing around the shaft, rod, or plunger in "a typical stuffing-box design" requires lubrication for proper operation. It is noted that this lubricant is provided by the fluid being handled as it flows through the slight clearance between the moving parts and the packing. He goes on to give a "desired leakage rate" of 8-10 drops per minute and to note that such visible leakage should not be misinterpreted as something more serious by inexperienced mechanics. Such leakage would obviously increase contaminant concentrations.

Danielson⁽⁶¹⁾ discusses how the operation of pumps handling fluids in petroleum process units can result in the release of air contaminants. He describes the various means of sealing pumps and then presents the results of a study to measure losses from pumps with packing glands and those with mechanical seals. During the handling of highly volatile hydrocarbons, it is shown that pumps in continuous service lose an average of 18.3 and 7.9 pounds per day for packed and mechanical seals respectively. This indicates that mechanical seals are far more efficient when running continuously. On spare or standby service, the packed seals were shown to be more effective, losing 1.8 pounds per day versus 4.4 pounds for mechanical seals. The amount of contents lost was obviously less when less volatile substances were conveyed. The largest leak encountered in the study was from a reciprocating pump on intermittent service handling LPG. Its leak rate was 266 pounds per day.

Other types of pumps described by Danielson include the canned, diaphragm, and electromagnetic types. All of these are devoid of seals and do not leak. A pressure-seal-type application is noted capable of reducing packing gland leakage.

Leakage from valves is another area of concern for Danielson. Of the valves of refineries which have been inspected in Los Angeles County, it was found that 16.5% of those in gaseous service leaked while 11.5% of those in liquid service leaked. Of those in the first category, 70% leaked less than 0.2 pounds per day. In the second category, 90% leaked less than 0.2 pounds per day. The remaining large leaks were of an average rate of 9.1 and 8.1 pounds per day respectively.

Browning⁽⁹⁹⁾, in a paper concerning the estimation of loss probabilities, gives some relative probability figures for failures of containing equipment under various inplant environmental conditions. Of interest is that the probability of a failure in a process system with generally screwed fittings is shown as being an order-of-magnitude greater than for systems with generally welded and flanged fittings.

One might consider that this also gives some indication of the relative leak resistance of such systems.

Templeton⁽¹⁰⁰⁾ notes that screwed connections have many disadvantages. Discussing them, he notes that leaks are difficult to seal, threads are subject to crevice corrosion, easily galled materials are difficult to tighten, and that "leaks from screwed joints may produce conditions on the exterior that will rapidly attack piping and valves." He further makes the point that welded piping systems give the maximum assurance of leak tightness.

Russell⁽¹⁰¹⁾ reports that spiral-wound gaskets with centering rings are normally specified for use with welding neck or lap joint flanges for "high reliability piping systems." He makes the point in his paper that the dimensional tolerances specified by industry standards can allow the outer portion of the spiral gasket to extend beyond the raised faces of a flange pair, a condition which can ultimately result in gasket failure or leakage.

A method of reducing gas leaks from flange closures is the subject of a paper by Fitzpatrick.⁽¹⁰²⁾ He reports on a particular problem with a reaction system in a polyethylene plant where rapid temperature changes resulted in undesirable leaks. The successful solution of the problem involved the rather novel application of Belleville springs on the closure bolting.

Baturin⁽¹⁰³⁾, discussing normal leakage rates from equipment and pipes in which gases under pressure are handled, states that "with acceptably sound equipment the leakage of a gas, depending on its molecular weight, is approximately 7-12 percent per hour of the internal volume of the equipment." He also presents a formula for more specifically estimating leakage rates, one which takes into account the pressure of the gas stream.

A recent news item⁽¹⁰⁴⁾ described the success of Sweden's largest chemical company, KemaNord, in achieving 8-hr workplace vinyl chloride concentrations of 1.5 ppm at two vinyl chloride plants. The article reports that typical previous performance was around 30 ppm. These "unusually low concentrations" were realized by the use of local exhaust ventilation at points in the process where vinyl chloride release was "particularly possible", and by mechanically tightening up the equipment train. The latter involved investment in new valves and replacement of numerous screwed couplings by flanged ones that could be tightened easier and more readily equipped with gaskets.

A more recent article⁽¹⁰⁵⁾ discusses the attempts of PVC manufacturers to reduce exposures by controlling fugitive emissions. As would be expected, the tightening of flanges, the use of welded or flanged couplings instead of "leak-prone" threaded couplings, investigation of better gasket materials and pump seals, the use of larger

capacity equipment, process changes to reduce the frequency of cleaning operations, and other subjects are receiving attention. Of interest is that the EPA "plans to insist on double-sealed or canned pumps (or an equivalent); the agency also will call for rupture disks under relief valves, to avoid leaks if a valve reseats improperly."

Conclusions

The information given above clearly indicates that, within any given chemical process plant, there are numerous sources of air contaminants. The most significant of these, from the viewpoint of quantity, are those involving process venting practices and the flue gases from combustion processes. Ludwig and Wiley both support the fact that venting practices are significant factors. That uncontrolled flue gas emissions also can contribute to exposures, both inplant and in the surrounding environment, is so well appreciated that further elaboration is unnecessary.

Since these two sources are of such significance, they have become a primary concern of the Environmental Protection Agency (EPA) and state and local air pollution agencies, mostly as a result of the Clean Air Act. Consequently, not only have emission rates and the number and location of sources been regulated, but this regulation has encouraged considerable research and development effort for pollution control systems. For this reason, it can be concluded that participation of NIOSH in such efforts is not warranted, unless of course it becomes evident in the future that the control methods being utilized are inadequate to eliminate these sources as significant inplant contaminant sources.

In this report, we are primarily concerned with those potential contaminant sources which more directly affect the inplant working environment. We have thus elaborated in the above upon such leaks as may result from "closed" process system components, and have noted the possibility of accidental releases due to equipment malfunction or failure. Utilizing the data presented, a knowledge of process plant design practices, and an appreciation of the difficulties involved in controlling exposures to low limits, we are logically and intuitively led to the following conclusions:

1. Process plant equipment trains, even those which are normally considered as representing, "closed systems," inherently contain numerous small sources of airborne contaminants. Generally speaking, every pipe joint assembly, valve stem, closure flange, relief valve seat, and opening into a vessel for the insertion of measurement devices or mixer/agitator driveshafts, etc., is a potential source which contributes to overall exposures.

2. For most slightly and moderately toxic substances, the application of general mechanical ventilation in enclosed areas or the placement of systems in the open (i.e. the layout of a typical hydrocarbon refinery) has been adequate to maintain contaminant concentrations at or below exposure limits.
3. Until possibly very recently, process engineering design groups did not consciously consider the effect on ambient contaminant concentrations of their choice of specific fitting or seal types. Systems components were generally selected on the traditional bases of cost, reliability (in the length of service sense), and performance of function.
4. With the advent of regulations requiring extremely low average and ceiling contaminant concentrations for highly toxic substances, general ventilation methods can no longer be considered solely adequate to maintain acceptable exposure levels. As proof, witness the difficulty of industry in complying with vinyl chloride standards and the experience of KemaNord. Their equipment and plants were not originally designed to be leak-tight to the extent which now has become necessary.
5. There is little specific information in the literature which allows an accurate estimation of the gas or liquid leakage rates from system fittings in either a relative or absolute manner, or which suggests how best such sources can be controlled or eliminated.

Possible Course of Action

It is evident that the feasibility of reducing work place contaminant concentrations by the proper selection and use of process equipment is being demonstrated by the efforts of PVC manufacturers. Their efforts are somewhat on an individual basis, however, and cannot be expected to result in design guidelines which are formulated and disseminated to other industries which utilize the same types of equipment. The potential benefits of eliminating such emissions at their source appear to be of substantial significance. Not only would worker exposures be reduced, but the possible additional costs involved might be overshadowed by reductions in product loss and ventilation system capacity.

There is considerable need at this time for some sort of consolidation of the available information on this basic control measure and the provision to industry of guidelines for the proper design of chemical process systems. Hence, it is recommended that a

research program be conducted to compile all available information and to attempt to present it in a form which allows appreciation by industry of the potential benefits of choosing equipment of maximum leak-tightness. The results of such a program would serve to identify data gaps for further research consideration. A 2 man-year effort over a time period of 1 year is considered reasonable for this task.

Some time in the future, NIOSH and OSHA might consider the formulation from these data of design codes for industry use. These might allow the estimation of total leakage rates from systems consisting of known numbers and types of fittings and couplings, might include construction and/or performance specifications for various fittings, and might attempt restriction of the use of certain "leaky" types under particular circumstances.

The National Electrical Code⁽¹⁰⁶⁾ contains standards for the use of electrical equipment in hazardous locations, i.e. locations where flammable gas concentrations are, or may be, present. The code assigns classifications including a "Group" (A-D inclusive) based on the ease of ignition of the substance, and a "Class," (I-III inclusive), based upon the type of operating environment. In a somewhat general manner, construction specifications are given for equipment to be used in the various classified locations, equipment "approval" is required for the Class of location and the chemical Group involved, and it is specified that equipment be marked to show the Class, Group, and operating conditions for which it is approved.

Standards or codes for equipment handling toxic substances could benefit from a similar format. One can envision Group assignments based upon the vapor pressure and the Threshold Limit Value of a substance, and Classes based upon general ventilation rates, proximity of employees to system components, location of equipment (i.e., size of room, outdoors, etc.), number of fittings per unit area, etc. Loss probability data, such as those presented by Brown, could be utilized in the code development procedure to ensure adequate system integrity over the life of the plant and to thereby reduce the potential for massive equipment failures.

Development of such codes or standards requires that a firm and complete body of data be available on the present performance characteristics of the equipment of concern. Since the research program recommended may identify numerous areas for research by NIOSH, EPA or industry, no attempt will be made to estimate the extent of efforts required to develop such codes at this time. This might be more properly achieved as a part of the program recommended.

4.4 CLEANING AND MAINTENANCE

Introduction

In 1973, a "loom fixer" in a cotton mill wrote to the S.C. Department of Health. He noted that "The looms are blowed off with an air hose

while everyone is working with the looms. This dust is terrible ... I have pulmonary emphysema."(107)

Wheeler and Sutherland⁽¹⁰⁸⁾ report that a single pump repair can release 1 to 10 pounds of vinyl chloride monomer (VCM) to the atmosphere while a once full line scavenged with an inert gas can still contain several tenths of a pound of VCM. They add, "rarely was provision made to control emissions from maintenance work."

These are the types of comments which can be found in the literature regarding the hazards involved in the cleaning of work places and the maintaining of equipment. That the operations are of a type which are difficult to characterize and are widely varying in nature can be well-appreciated. In the following, a brief look is taken at these operations, and some ideas presented on what might be done to reduce exposures.

Cleaning Operations

The primary cleaning methods utilized in industry include:

- Manual wiping with a dry or solvent soaked rug;
- Use of hand or mechanical brushes;
- Use of a scraper;
- Wet mopping;
- Use of a wet sponge;
- Hydroblasting;
- Steam-cleaning;
- Use of compressed air; and the
- Use of vacuum devices (for solids and liquids)

The only common feature of all of these is that by some physical and/or chemical action a contaminant is dislodged from the surface it is adhering to, collected, and removed from the immediate environment for disposal. The locations and circumstances under which each method may be used vary considerably.

It is difficult to approach this subject in the manner in which other engineering control problem areas have been investigated. The appropriateness of various methods appears to have been given only cursory treatment in the literature. Any guidelines which have been stated can be summarized in but a few phrases. These are: use wet methods for dusty substances, or use vacuum devices instead of "blowing"

techniques; limit cleaning operations to periods when the least number of employees are present; use "safe" solvents if any are needed; provide workers respiratory protective devices when toxic substances are involved; and finally, minimize releases of toxic agents into the work area by use of process change, local exhaust ventilation, enclosure, etc.

The latter of these recommendations is, of course, the most satisfactory. If a toxic substance is not "free" in a work area, then it cannot harm a worker attempting to clean the area. Unfortunately, however, this solution is not one which can be solely relied upon. As long as equipment trains leak and containers or packages of toxic substances are handled in the working environment, there will be need for periodic housekeeping activities to remove accumulations from the floor, from machinery, from walls, and from overhead fixtures.

Looking at the above list of cleaning methods, one can make some observations concerning how excessive exposures may occur. Where a rag is used with some solvent, the solvent vapors may be the problem. This might also occur if solvents were used in wet mopping or with a sponge.

The use of a brush to sweep up dusty substances, or a scraper to dislodge built-up cakes of dry substances, can disperse dust into the air, especially if work is being done at some elevation above the floor. The use of compressed air to "blow" dust from surfaces is probably the most hazardous technique of all.

Hydroblasting and steam cleaning are essentially wet methods which might, on first consideration, appear to be methods which would suppress the generation of contaminants. However, in at least one situation we are aware of, hydroblasting of equipment to remove a solid which crystallized out of leaked solutions resulted in short-term contaminant concentrations which were 2-3 times that normally found (and substantially above permissible exposures). Because of the temperatures and forces involved, steam-cleaning may be assumed to be capable of producing similar conditions under some circumstances.

It is the use of vacuum devices, i.e. vacuum cleaners, which appears to be the most satisfactory method of collecting contaminants. Since such devices utilize the same principles as local exhaust systems, i.e. they provide a sufficient air velocity at a "hood face" to dislodge and thereby "capture" contaminants, and a sufficient "duct velocity" to transport contaminants to an air cleaning device, one might consider their use of the utmost desirability. Such devices are available which not only can vacuum dusts but also pools of liquids.

Discussion and Conclusions

There are two observations which can be made about these methods. The first is that some are clearly more appropriate for use than others

depending upon the physical and chemical characteristics of contaminants and the location from which they are to be removed. The second is that the use of vacuum devices has the potential to substantially reduce the generation of air contaminants where their use is practical.

Recommendations

Both observations made suggest that some worthwhile studies may be conducted by NIOSH in this subject area. For example, since some methods must be considered to be better than others under certain circumstances, NIOSH might attempt to define what these circumstances are based upon the cleaning problems commonly found in industry. This could be accomplished by a survey investigating the experience of plants in a variety of industries and the reductions in contaminant concentrations which might be achieved with alternative methods. The results of the survey, together with other "good practice" type information could then be utilized to produce some sort of booklet or manual to be provided industry. Topics would include discussions of the need for keeping a workplace clean, the types of cleaning problems typically encountered, the cleaning methods available, and the appropriateness of the various methods in various situations. Within these categories, discussions could be given of the relative safety of various solvents and cleaning fluids, the difficulty of achieving permissible exposure levels by any means if the workplace is significantly contaminated, and other pertinent topics. An 8 man-month effort over a time span of 6 months would probably be adequate for such a program.

One question was raised during consideration of the use of vacuum cleaners that also may deserve some attention. This involves the fact that the types of self-contained vacuum units commonly utilized are analogous in many respects to a local exhaust system which provides for cleaning and subsequent recirculation of exhaust air back to the working environment. Whenever the topic of recirculation of exhaust air is addressed, a primary factor given consideration is the need for the exhaust air to be sufficiently free of contaminants. The analogy of large-scale recirculation systems with vacuum cleaners lead to the observation that similar attention might be given to these devices to ensure that respirable toxic dust collected is not passed through filters and blown back into the workroom air. A small program to look at this perceived problem area would simply involve the collection of pertinent information from the manufacturer of such filters and possibly some limited experimentation to determine if the amounts of contaminants which pass through might be significant for some toxic substances. A 2 man-month effort over a time span of 2 months would probably be adequate. This recommendation is presented simply as an idea. We have no knowledge if this might be a realistic problem area.

Maintenance

A dictionary definition of the above word indicates we are concerned with the act of keeping implements used in an operation

or activity in an existing state of repair, efficiency, or validity. From an occupational health viewpoint of the matter, we may restrict this definition to those operations which require a worker to open or approach a device containing or releasing toxic substances and to perform some activity in its immediate vicinity. Included would be such diverse operations as the changing of a filter media, the repair or replacement of a pump packing, the tightening of a leaking flange, and similar acts.

These operations, because of their characteristic of being possibly necessary at any point in an equipment train, would not appear to have been given specific consideration for the provision of engineering controls, except, of course, where they are repeatedly conducted in a specific location. Thus, one can safely make the statement that engineering controls are generally unavailable for them.

There is, however, one approach to provide effective control which can be envisioned, one which might at first be considered a bit far-fetched but which may be feasible with current technology. This entails the development of self-contained, portable, local exhaust systems with internal air cleaning devices for vapors and fumes.

Ideally, such devices would have the following features:

- Be not much larger than a 55-gallon drum,
- Be electrically powered,
- Be provided wheels for portability,
- Have a stiff but flexible hose (i.e. exhaust duct) which is self-supporting,
- Have lightweight open or partially enclosing exhaust hood attachments for the open end of the exhaust duct,
- Be provided with a limited number of air cleaning sections which are interchangeable within the basic unit, each being effective for a large number of chemicals of similar chemical structure (i.e. ketones, alcohols, aldehydes, etc.) and
- Be of reasonable cost.

One can imagine that such units might find widespread use in industry if they were practical and effective. Not only might they be used for "one-shot" maintenance work, but also, in small firms, as relatively low-cost, easily installed units for reducing overall contaminant releases for both EPA and OSHA compliance purposes. In all types of firms, they might find use as emergency control measures for controlling small but potentially hazardous leaks.

The development of such devices into actual working prototypes might require the expenditure of considerable resources, or alternatively, might be simple and require little effort depending on the type of contaminant to be treated. For flammable ketones and the like, the air cleaning section might simply include an incinerator followed by a catalytic converter, much like the controls on automobiles. For other substances, more sophisticated measures may be necessary.

Given these uncertainties, the first step in any such program would involve a user need and engineering feasibility study. Such a study would review the list of toxic substances regulated by OSHA, determine which are most hazardous from acute exposures which can be conceived of in industry, survey plants utilizing these substances to investigate how excessive exposures during maintenance work are now avoided, determine the ideal operating characteristics of the device, and review the state-of-the-art of air cleaning technology to suggest reasonable development approaches. This might require a one man-year effort over a time span of nine months.

4.5 DRYING AND CURING OVEN USE

Introduction

In the industrial terminology, "drying" is defined as "the removal of a liquid from a solid by thermal means."⁽⁸⁾ There are many situations in industry in which drying is beneficial. These include (1) facilitating handling in subsequent operations, (2) allowing satisfactory use of final product, (3) reduction of shipping costs, (4) increasing capacity of equipment used in following processes, (5) preservation of a product, and (6) treatment of waste products, among others.

Much of the equipment used for drying purposes are also used for "curing", i.e. the application of heat to bring about a physical or chemical change in a substance.

A logical classification system for this equipment is based on the method used to transfer heat to the material being dried and/or cured. The first major category includes direct dryers in which hot gases are in direct contact with the material, and carry away any vaporized substances to be exhausted. The second category includes indirect dryers in which the drying heat is transferred to the moist solid through a conducting wall. In this type of dryer, any vaporized substance is removed independently of the heated air. A third, limited-use class includes radiant-heat and dielectric-heat dryers. The operation of the former is based on the generation, transmission, and absorption of infra-red rays. The latter rely on heat generation within the solid when it is placed in a high frequency electric field.

Direct Dryers

Direct dryers can be sub-categorized with regard to their operating mode, i.e., continuous or batch. In the continuous type, operation is not interrupted as long as wet feed is supplied. Any continuous dryer can be operated intermittently or on a batch basis if the need arises. Batch dryers can only operate on a fixed amount of wet stock for a fixed time cycle. These dryers operate at atmospheric, or near-atmospheric pressures.

Continuous tray dryers function by circulating heated air across a wet material until sufficient drying has occurred. This can be accomplished in a vertical turbo-dryer, consisting of a series of stacked trays through which the material is successively dropped. In the upper stages, hot air is brought across the trays by a vertical series of exhaust turbines.

Tunnel drying involves the placement of material on small trucks and movement of the trucks through a hot gas tunnel in a semi-continuous fashion. Airflow in the chamber can be either parallel or perpendicular to the movement of the trucks. In the former, the heated air may flow with or against the material flow. Effective control of the humidity and temperature is more easily achieved, however, if perpendicular air flow is employed.

Continuous through-circulation dryers can be used when the material to be heated is permeable. Heated gases are blown through the bed of wet material as it passes continuously through the dryer on a moving screen. Drying rates are increased due to the increased effective surface area and the decreased travel distance for the internal moisture.

Spray drying is accomplished by establishing a highly dispersed liquid state in a high temperature gas zone. The material to be dried must therefore be amenable to atomization. The spray droplets formed fall through a chamber which has an upward flow of heated air. Because the surface area-to-volume ratio of the material in droplet form is quite large, drying is accomplished quite rapidly, usually in less than 30 seconds.

A direct rotary dryer consists of a cylinder revolving at a slight horizontal tilt. Hot gases pass through the cylinder, drying the material as it is introduced at the elevated end. The airflow may be either counter-current or parallel to the material flow. The inside of the drum is generally fitted with a series of baffles to lift and agitate the material. Some rotary dryers operate on an indirect-direct basis, with the gases heating the cylinder and contacting the material directly.

Continuous sheeting dryers convey a continuous length of material, such as a fabric, rug, paper, or textile through a chamber in which it is exposed to a heated air stream. The configuration in which the

material is suspended is dependent upon the substance being dried. Some materials must be kept taut during drying, others can be draped in loops. In all cases, the material must be strong enough in its wet state to withstand any tension applied.

The final dryer in this category is the pneumatic conveying model. Often performed in conjunction with grinding and pulverizing, removal of moisture occurs when the material to be dried is dispersed in a hot gas zone and transported at high velocities. Cyclones, bag collectors or wet scrubbers are used to retrieve the dried product.

There are two types of dryers which operate in the direct batch mode. The first is a through-circulation type in which the material is positioned on stationary trays through which hot air is forced. The second type consists of tray and compartment dryers. These dryers support material on trays across which hot air is passed. The method of suspension is dependent on the physical characteristics of the solid. Proper operation of these units requires a constant, uniform flow into all parts of the chamber, since the material to be dried remains stationary.

Indirect Dryers

Cylinder dryers are employed to continuously treat paper, cellophane, and some textiles. The cylinder is steam heated, and drying generally occurs at atmospheric pressure, although a few designs incorporate a vacuum chamber to facilitate drying. The process may be enhanced by blowing air across the surface. Removal of any wet air is usually accomplished by the use of hoods and exhaust fans.

Drum dryers are similar to cylinder dryers. Here, a slurry, paste, or liquid solution is applied to the exterior of the heated drum. In less than one rotation, the material, now dried, is scraped off the drum by a fixed blade and falls onto a conveyor belt. Operations ensue at atmospheric pressure or under vacuum, and the vapor is removed by local ventilation.

Steam tube rotary dryers are similar to direct and indirect-direct rotary dryers. They consist of a rotating cylinder in which material is dried as it traverses the length of the unit. In this situation, however, drying is totally indirect, with the rotating shell being heated by tubes or cylinders placed within it. These devices can be used to continuously dry granular or powdery materials that must not be contaminated with combustion products.

There are four types of machines used for indirect batch drying; the agitated pan dryer, the vacuum rotary dryer, the vacuum tray dryer, and the freeze dryer. These are easily adapted to work in vacuum conditions, thus lowering operating temperatures.

The agitated pan dryer consists of a circular tray which is steam heated from underneath. The material in the pan is stirred by an agitator so that fresh material is constantly coming into contact with the bottom of the pan. Solvent recovery is attainable with this device and the device is particularly useful for small batches.

Vacuum rotary dryers consist of a large, stationary cylinder to which heat is applied through a jacket in the shell. A set of internal paddles agitates the substance. Vacuum is applied and maintained throughout the drying cycle. A less common type of unit has a rotating jacketed shell.

Vacuum tray dryers consist of a chamber containing shelves. The shelves are hollow and connected to headers through which the heating medium is supplied. Conduction of heat occurs between the shelves and the metal trays in which the material is placed. Vacuum allows low temperature drying and solvent vapor recovery.

In a freeze drying process, frozen solvent is removed by sublimation. The machinery may be of the shelf drying, cylindrical vessel, or horizontal rotary vacuum design. An advantage to prefreezing the material is that the warming temperature can be lowered to the point where damage will not occur to the substance. The loss of volatile constituents is also minimized, thus making the process attractive for food processing.

Radiant-Heat and Dielectric-Heat Dryers

Radiant heat dryers transfer radiant energy to the material. This can be accomplished with infrared lamps, electric resistance elements, or incandescent, gas-heated refractories. The latter add the advantage of convective heating. Infrared drying is used primarily in baking or drying paint films or heating thin layers of material. It is employed infrequently in the chemical industries.

Dielectric-heating involves heat generation by use of a high-frequency electromagnetic field. Since these dryers operate on the principle of heat generation within the solid, the potential for drying large objects is being explored. A severe drawback is the increased power demand, which can be ten-fold the requirements of conventional machinery.

Literature Review

The ACGIH Industrial Ventilation Manual⁽¹¹⁾ contains criteria for the control of employee exposures to contaminants from drying ovens. The dryer illustrated is of a type used for continuous processing. The controls recommended include a slot type hood located around the top portion of the entrance or exit doors and a canopy type which also is installed over these doors. For the slot hood, an exhaust volume of 100 cfm per sq ft of door area plus 1/2 the products

of combustion is recommended. For the canopy, the recommended rate is 200 cfm per sq ft of hood face plus the same correction for combustion products. Notes on the illustration suggest a separate vent be added for products of combustion, and if flammable solvents are evolved, that the oven ventilation rate be adjusted to maintain solvent concentrations at or below 25% of the lower explosive limit (LEL).

The National Fire Codes⁽¹⁰⁹⁾ also address the need for ventilation of ovens and furnaces to control flammable or toxic vapors. However, they simply give a calculation procedure for determining the ventilation rate necessary to maintain concentrations at 25% of the LEL in continuous process ovens. A procedure with similar objectives is given for powder fusing or curing ovens. Batch process ovens are reported to usually require no more than 380 cfm per gallon of solvent present.

The Michigan Department of Health⁽¹¹⁰⁾ notes that although oven ventilation system design involves basic application of well-known principles, it is often conducted poorly. The authors report that oven fumes, sometimes including carbon monoxide, are often released into the workroom, as are a variety of solvents and other substances found in the drying or curing products. Particular problem areas noted include inlet and outlet openings in continuous mechanized ovens and opened doors in batch ovens. While suitable exhaust from the oven interior which causes an indraft into all openings is noted as being "sometimes" satisfactory in conveyORIZED units, it is recommended that ventilation system designs include local exhaust hoods at inlet and outlet openings and at batch oven doors.

Feiner and Kingsley⁽¹¹¹⁾ somewhat disagree with other sources addressing the control of continuous ovens. They recommend that make-up air enter the enclosure through the work entrance opening, traverse the entire heating zone and be exhausted from the dry end of the oven. Of interest is their comment that "in a number of continuous ovens, particularly for cloth coating machines, the nature of the different products manufactured is such that conditions will vary due to different coating materials used, different concentrations of material in the solvent, varying thicknesses of coat applied, changing temperatures, and adjustable conveyor speeds. Under these circumstances, ventilation should be provided to satisfy the worst possible conditions."

Feiner and Kingsley also discuss the use of "air seals." These are described as vestibules attached to the ends of an oven where the work enters and leaves; their purpose being to act as an expansion chamber in which the air leaving the oven proper can cool and contract. It is noted that these are "usually provided at ovens processing large pieces of work where the entrance and exit openings are so large that the ventilation rates required for maintaining safe atmospheres within the oven are not high enough to maintain controlling velocities through the large area of openings." These "air seals" are more clearly described in other sources which equate them to "air curtains" installed at oven openings.

Constance⁽¹¹²⁾ simply recommends an exhaust volume of 100 scfm per sq ft of booth cross-section for drying, baking, and curing ovens. For the door opening of a continuous washer, dryer or oven, he gives canopy hood design criteria of 150 scfm per sq ft of door opening or 200 scfm per sq ft of hood face.

Hemeon⁽¹¹³⁾ discusses exhaust system design considerations for hot processes. Because air streams from hot surfaces behave differently than those from cold surfaces, it is noted that the operating temperature of a dryer must be included as a design parameter. Hemeon states that when the air in an exhausted enclosure is hotter than the ambient air, the enclosure may permit the escape of contaminated air in some situations. He writes, "This phenomenon may sometimes be observed in drying ovens having small openings or cracks at the top, or which are open at the ends..." The thermostatic head due to the temperature difference can be determined by Hemeon's equations and counter-balanced by creation of a negative static pressure within the enclosure. If the pressure difference is equal to or greater than the thermostatic head, no leakage will occur.

Boyle and Novack⁽¹¹⁴⁾ have developed a set of equations for calculating the dilution ventilation requirement to maintain concentrations at or below 25% of a LEL in batch process ovens. They prefer their method of determination to the NFPA requirement of 380 cfm per gallon of solvent because the latter "does not always insure a ventilation rate at 25% of the LEL."

There are several variables, according to these authors, that must be considered in the determination of a safety factor value. These include: (1) elevated operating temperature, (2) thicker coating of material, (3) excessive oven loading, (4) alterations in coating material diluent ratios, (5) changes in diluent, (6) variations in air drying time between coats, and (7) poor oven circulation.

Danielson⁽⁶¹⁾ reports that dust can be a problem in any dryer in which the material is agitated or stirred during drying. Those which are listed as "prolific" dust producers include direct-fired rotary dryers, flash dryers, and spray dryers. Types noted to produce less dust are indirect-heated rotary dryers, pan dryers, and cylinder dryers. Tray dryers, sheeting dryers, and dryers for massive solids are noted as possibly emitting no dust. In general, he states that emissions may include vapors, mists, odors, and smoke whenever an organic liquid is evaporated. Also generally addressed by this source is the necessity for controls for many specialized ovens used in industry. Among these are included printing system ovens, can lithograph ovens, paint baking ovens, and others.

Discussion

There are two distinct reasons to control the environment in and around a drying oven aside from the obvious requirement of providing

effective heating and/or moisture removal. The first source of concern is the maintenance of a low concentration of flammable solvent vapor to eliminate the possibility of fire or explosion. The second is to ensure that toxic contaminants are not released into the breathing zones of workers.

As noted by the Michigan Department of Health, oven ventilation system design involves the application of basic principles. This statement must be agreed with. Review of the literature indicates that the factors which must be given consideration are many but can each be taken into account with relatively simple and available technology.

What is of concern is that the designing of an adequate exhaust system for such equipment requires that the designer be thoroughly familiar with all the various factors which must be given consideration and with the calculation procedures and techniques available to properly do so. It is clear that oven ventilation design is now a subject to be approached only by persons experienced in the field. Hence, comments in the literature that ovens are often poorly designed can be accepted as reasonable, especially since those most common literature sources which address the subject (e.g. NFPA and ACGIH) do not discuss many important factors. Discussions of these are only found in such sources as Feiner and Kingsley, sources which are not easily available and which are rather qualitative in nature.

Conclusions and Recommendations

From the above, the conclusion is reached that engineering controls for drying and curing ovens are available and adequate but that the factors which can lead to ineffective control are many and not sufficiently stressed. Consequently, it is recommended that NIOSH consider a program to review the state-of-the-art of oven ventilation design, to identify and fill identified data gaps (e.g. how to control emissions from types of dryers other than those which resemble tunnels or boxes), and to present the correct procedure for enclosure and ventilation system design of these units in some sort of ventilation guideline manual. Conducted by a firm which specializes in this subject area, such a program might be completed with a 6 man-month effort over a time span of 5 months.

4.6 GRINDING, CRUSHING, AND SCREENING

Introduction

Many industries utilize grinding, crushing, and screening equipment to effect size reduction or dispersion of solids or pastes. The intent of this discussion is to review the types of equipment commonly used for these purposes, and to examine the available information pertaining to the control of dust or vapor emissions resulting from their use.

Crushing and Grinding

Size reduction refers to the mechanical reduction in size of solid particulate material. Two of the principle methods of achieving size reduction are crushing and grinding, but the terms are not synonymous. Crushing generally refers to a relatively slow compressive action on individual pieces of coarse material ranging in size from several feet to under one inch. Grinding is performed on finer pieces and involves an attrition or rubbing action as well as interaction between individual pieces of material. Pulverizing and disintegrating are terms related to grinding. The former applies to an operation producing a fine powder; the latter indicates the breakdown of relatively weak interparticulate bonds, such as those present in caked powders.

Jaw crushers are employed for primary crushing of hard materials. The crushing cavity is formed by two wear plates, one rigid and one moving. The motion of this latter plate varies with the design, but the essence of the movement is to crush the material until pieces are of a size to drop through an opening between the plates.

A gyratory crusher consists of a cone-shaped pestle rotating within a cone-shaped bowl. The spacing between the two faces diminishes toward the bottom. Units can be used as either primary or secondary crushers.

Roll crushers either contain two rollers which rotate towards each other at a fixed, set distance, or simply one roller which revolves downward into a "nip" between the roller and a rigid breaker plate. To increase effectiveness, the roller usually has some type of protuberance to grab the material and force it into the gap.

Disk mills can be used for either crushing or grinding. The various forms include the rotary crusher, rotary grinder, stone mill and colloid mill. The rotary crusher simply consists of two faces revolving at different speeds within close proximity of one another. The rotary grinder operates on the same principle but provides much finer grinding.

Roller mills are used to process powders and pastes. In the most common roller mills, the substance is passed through closely spaced rollers which revolve at different speeds and in opposite directions to effect some degree of dispersion and/or size reduction. Removal is accomplished by means of a scraper on the final roller. Variations of roller mills include the pan type, the ring roller, and the ball roller.

Hammer crushers can be used for either crushing or pulverizing. The hammers are mounted to a rotor shaft which runs in a housing containing grinding plates or liners. The rotor is enclosed by a

cylindrical screen or grating through which the product is removed. The grinding action results from attrition, while the crushing arises due to impact. To attain effective pulverization, hammer mills are employed which differ from hammer crushers in specifics, but not in basic design.

Cylinder mills or tumbling mills consist of a horizontally-mounted chamber containing a loose packing of grinding media which move about the grinding charge to provide the necessary impaction and attrition. The media can be balls, tubes, rods or pebbles.

Other machines used for grinding and crushing include jet mills, pan crushers, non-rotary ball or bead mills, dispersion mills, and others. A number of these were previously described in the industry evaluation for paint and coatings manufacturing.

Screening

Once the size of individual pieces of material has been reduced, it is often necessary to assure size uniformity, or at least a maximum cut-off. This can be accomplished through several techniques, including screening, centrifugal classification, pneumatic classification, and aqueous classification. Screening is the most commonly used method and is of most concern to this discussion.

Matthews⁽¹¹⁵⁾ writes that "Screening is a unit operation that is an essential part of many different processes". It involves the mechanical separation of particles on basis of size, and is also known as sizing, sifting, sieving, or separation. There are three types of screen surfaces: (1) parallel bars, (2) punched plates, and (3) woven wire or fabric. In general, these are in order of increasing fineness. Screening surfaces are generally moved or vibrated to facilitate material flow.

Perry⁽⁸⁾ divides screening machines into five categories: (1) grizzlies, (2) revolving screens, (3) shaking screens, (4) vibrating screens, and (5) oscillating screens. In general, grizzlies are used for the coarser materials and oscillating screens for the finest.

Grizzly screens contain a set of parallel bars held at a specified spacing. These can be stationary or vibrating and are often used prior to a primary crusher to remove fines. Stationary grizzlies are often used to retain occasional pieces too large for processing by following plant equipment.

Revolving screens (trommel screens) consist of a cylindrical frame surrounded by a mesh wire cloth or a punched plate. Mounted on an incline, the material to be screened enters the rotating cylinder on the upper end, the oversize exits at the bottom and the desired product falls through the openings. Low capacity and efficiency have limited the use of these screens.

Shaking screens are mounted on a slightly inclined rectangular frame which is suspended by cables or rods. The surface itself can be a punched plate or wire cloth. The raw material is deposited on the screen at the upper end and is advanced down the slope by the forward stroke of the screen.

Vibrating screens fall into two subcategories, (1) mechanically vibrated screens and (2) electrically vibrated screens. The former are similar to the shaking screens described above but have a much higher capacity and efficiency. Electrically vibrated screens are drive by electromagnets at intense, high-speed, low amplitude vibration. These are commonly used in the chemical industry for handling light, fine, dry materials and powders.

Oscillating screens operate by applying an oscillating motion in the plane of the screening surface. These are fine screens used for light, free-flowing materials. Reciprocating screens, gyratory screens, and gyratory riddles are also used in industry.

Controls

The fact that hazardous dust exposures may be produced in size reduction and separation processes is fairly obvious. These operations involve small particles which can easily be suspended in air and released to the plant environment if proper controls are not utilized. Where organic solvents are used in paste or ointment formulations, solvent vapors may also be evolved.

Both Hemeon⁽¹¹³⁾ and the ACGIH⁽¹¹⁾ recognize the potential for dust exposures from classifying screens. Hemeon states, "Vibrating and rotary screens may produce tremendous quantities of dust which can be controlled only by complete enclosure. Indeed, it is possible to enclose them so well as to eliminate the need for any exhaust." Nevertheless, the ACGIH presents a combined enclosure-exhaust system for both flat-deck and cylindrical screens. Called for are a face velocity of 200 fpm for the flat deck screen and 100 cfm/sq ft circular cross section for the cylindrical screen. In the first case, the minimum given is 50 cfm/sq ft of screen area, while in the latter it is 400 cfm/sq ft of enclosure opening or a face velocity of 400 fpm.

Baturin⁽¹⁰³⁾ devotes a chapter in his book to the "Local Exhaust of Dust in Crushing, Pulverizing, and Transporting of Free-Flowing Materials". In it, he provides design criteria for the construction of local exhaust systems for many of the pieces of equipment discussed above, including jaw-type and roll-crushers as well as vibrating sieves. His recommended exhaust volumes for the crushers are presented as a function of the volume of the casing, with the values ranging from 300 to 700 cfm.

The ACGIH manual also contains design criteria for the ventilation of tumbling mills of the trunnion and stave types, and mixers and mullers used in foundry operations.

Danielson⁽⁶¹⁾ provides brief notes on the basic requirements of a system ventilating this machinery. Grinders and crushers are noted to require enclosure with a 200 fpm face velocity, while mixers are reported to require 100 to 200 fpm. He also, somewhat confusingly, suggests 500-1000 fpm through enclosure openings.

When flammable solvents are used as the vehicle for pastes to be processed, all duct and hood velocities must be reconsidered, bearing in mind the allowable concentration of the contaminant in the work place environment and the lower explosive limit (LEL) of the solvent.

Discussion

Depending upon the equipment used, the materials handled, and operating conditions, many of these operations may result in exposures if uncontrolled. These may occur as a result of the actual operation or as a result of loading and unloading the equipment. The controls recommended throughout the literature are of two types; exhausted enclosures for equipment, and various open hoods placed near loading and unloading hatches. For certain types of equipment used in specific industries, specific design criteria are available. For others, only the need for controls is expressed together with the general approach for providing them.

There is cause to consider whether it would be advantageous for NIOSH to catalog these equipment, determine their points of contaminant emissions, and the specific control design criteria applicable to each type. While much of the equipment of concern is commercially available with enclosures and exhaust duct take-offs already attached, some of it is not and requires the user to provide such controls. If a sufficient body of data is compiled, NIOSH may then consider the development of ventilation guidelines for these equipment. To be noted is that attempts to accomplish this latter task were aborted in a previous program to develop recommended industrial ventilation guidelines when sufficient data of confirmed validity could not be found.

Recommendations

It is recommended that NIOSH consider a research program with the objectives of cataloging the types of grinding, crushing, and screening equipment available; compiling available data on control of emissions from these equipment; identifying and filling data gaps; and developing engineering control guidelines for the equipment and its attendant material transfer points. It is estimated that an effort of 24 man-months over a time span of 12 months would be appropriate for such a program.

4.7 LABORATORY OPERATIONS

Introduction

The term "laboratory operations" is used here to include small-scale experimental research and testing activities conducted by academic, research, and industrial operations. Operations of concern are those with the potential for creating excessive exposures of laboratory personnel to airborne contaminants.

Laboratory operations are highly variable and, to a large degree, unpredictable in their nature. The types of air contaminants which can be generated and their modes of generation are unlimited. Some operations will produce air contaminants in a "normal" operating mode such as with the evaporation of volatile liquids from storage or process vessels. With many operations, contaminants may be produced accidentally due to spillage, container failure, or explosion.

General practice in protecting laboratory personnel from air contaminants involves the use of general purpose protective facilities. The most common protective measure is the use of ventilated enclosures such as laboratory hoods, glove boxes, and biological cabinets. These enclosures also can be designed to protect personnel from explosions, fire, and equipment breakage. To a lesser extent, free-standing, open exhaust hoods also are used in laboratories for air contaminant control.

Existing Ventilation Criteria

Ventilation criteria are contained in the Industrial Ventilation Manual⁽¹¹⁾ for three types of ventilation equipment used in laboratories: glove boxes, laboratory hoods, and open hoods. Ventilation criteria for laboratory hoods are also found in References 116 and 117. The criteria found in these sources are consistent in that, in all cases, operations are classified according to the toxicity levels of the contaminants generated, and minimum ventilation rates are prescribed for each contaminant class. However, there are differences in the contaminant class definitions and in the ventilation rates prescribed. None of these sources present supporting data for their recommended ventilation criteria.

Criteria for the use of open hoods are applicable to many laboratory operations. In addition to those found in Reference 11, additional criteria are presented in References 118 and 119. These criteria generally are based on the same principles of open hood operation, and the design and operational requirements are consistent.

Ventilation criteria also exist for laboratory operations involving specific types of air contaminants. Criteria for the control of radioisotopes and carcinogens have been published as Federal Regulations. (120,121)

The control of biological agents presents a problem which is different from other contaminant control problems in that two-way contamination

control generally is required. In addition to protecting laboratory personnel from biological agents, it is necessary to isolate the biological materials from contaminants in the laboratory environment. Approaches to designing biological cabinets have been published,⁽¹²²⁾ but no comprehensive guidelines are available.

Identification of Problem Areas

Problem areas in the ventilation of laboratory operations can be identified as shown in Table 6 by defining combinations of contaminant types and ventilation methods. Entries in the table indicate the existence of ventilation guidelines for specific combinations.

From Table 6, we can see that ventilation guidelines exist for nearly all combinations of contaminant types and ventilation methods of practical interest. The only exception is for biological cabinets which, as discussed above, represent a unique problem of contaminant control. Thus, the need for ventilation guidelines for biological cabinets is the first problem area identified. The second problem area is a need to verify the effectiveness of the existing guidelines for other ventilation methods. This latter problem stems from the lack of supporting data for the existing guidelines.

Discussion of Problem Areas

Biological Cabinets

Experiments with biological agents often entail the dual requirements of protection of personnel from the agents and isolation of the agents from atmospheric contaminants. These requirements can be met by means of a biological cabinet which provides an internal, filtered, recirculatory airflow which protects the experiment from external contamination. Other features of the cabinet prevent escape of contaminated air from the cabinet.

Biological cabinets are in use in universities, research institutions, and commercial laboratories where experiments are conducted with biological agents. Such cabinets are manufactured and sold by a number of companies. However, at the present time, there are no generally accepted design or operational criteria for these cabinets. Consequently, there is no way of knowing whether laboratory personnel are adequately protected against exposures to the agents involved in the experiments.

We suggest that a study be initiated for the purpose of evaluating the present state of the technology of biological cabinet design. The objectives of the study should be:

1. To classify biological agents and to define exposure limits appropriate to each class of agents,

TABLE 6

Problem Areas in Ventilation of Laboratory Operations

<u>Contaminant Types</u>	<u>Ventilation Methods</u>			
	<u>Open Hood</u>	<u>Laboratory Hood</u>	<u>Glove Box</u>	<u>Biological Cabinet</u>
Nuisance Materials	11, 118, 119	11, 116, 117	NA	NA
Low Toxicity Materials	11, 118, 119	11, 116, 117	NA	NA
High Toxicity Materials	NA	11, 116, 117	11	NA
Radioisotopes	NA	11, 120	11, 120	NA
Carcinogens, Mutagens & Teratogens	NA	121	11	NA
Biological Agents	NA	NA	NA	

Notes: Numerical entries indicate references to existing ventilation criteria.

NA = not applicable (not of practical interest).

2. To classify biological cabinets in terms of their applications and characteristic design parameters,
3. To determine the performance characteristics of biological cabinets in terms of exposure control as a function of cabinet design and operational variables, and
4. To formulate guidelines for the design and operation of biological cabinets.

It would be logical to conduct this study in phases with the first phase devoted to the collection and analysis of existing information. This phase would serve to identify the information gaps and to develop a program plan for later phases wherein these data gaps would be eliminated.

Verification of Existing Guidelines

It is also suggested that a study be initiated with the purpose of verifying the effectiveness of existing ventilation guidelines for laboratory operations. The objectives of the study should be:

1. To develop a procedure for measuring the performance of laboratory hoods and glove boxes which is easier to use than existing measurement methods,
2. To characterize "typical" releases of air contaminants in laboratory operations and to develop test methods for simulating releases of various magnitudes,
3. To measure the performance of laboratory hoods and glove boxes using the improved performance measurement procedure and release simulation methods. Performance measurements should be made under broad ranges of conditions both within and external to the hoods and glove boxes, and
4. To formulate revised ventilation guidelines for laboratory operations based on the performance measurements. Such guidelines might be in the form of a manual discussing all aspects of health and safety in the laboratory. Topics might include hazards in general, a list of "preclassified" chemicals, ventilation and other contaminant control techniques, protective clothing, spill and accident response, safe operating procedures (i.e., various "do's and don'ts"), etc.

This study could be conducted most economically by a field test program conducted with existing ventilation equipment.

Summary of Program Recommendations

Two programs have been recommended for the development and validation of ventilation guidelines for laboratory operations. Suggested durations and levels of effort for these programs are listed below.

<u>Program</u>	<u>Duration</u>	<u>Effort</u>
Biological Cabinet Guidelines (Phase 1)	9 months	1/2 man-year
Existing Guidelines Validation	18 months	2-3 man-years

4.8 MATERIAL HANDLING OPERATIONS

4.8.1 INTRODUCTION

Within the broadest sense of the term, "material handling" can be interpreted to include every type of industrial operation in which a substance in any form is moved or processed. However, since the processing of substances involves equipment or procedures which are covered separately in this report, and/or are unique unto themselves, the phrase is limited here to the operations involved in simply transporting materials or filling or emptying their containers. In this definition is not included the use of such principally individual units as industrial trucks, tractors and trailers, cranes, hoists, etc., nor the use of piping systems to transfer liquid.

4.8.2 BULK HANDLING SYSTEMS

Buffington⁽¹²³⁾ and others^(8, 124) describe the various mechanical conveyors and elevators used throughout industry. It is rather commonly noted that few bulk solid handling systems are complete without a dust control unit. Trouble spots noted include inlet and discharge points, and long chutes with free-falling material. Elevators are noted as requiring dust pick-up connections at both head and boot sections. Ventilation of bins into which materials are discharged is also suggested. In the following, the various controls suggested in the literature for these equipment are described and discussed more fully.

Belt Conveyor Transfer Points

Literature Review

Morrison⁽¹²⁵⁾ notes that "belt conveyors emit dust almost exclusively from two points - at the tail pulley where material is received from prior equipment, and at the head pulley where material is discharged". Appropriately, he reports that the amount of dust released at a transfer point depends upon the physical characteristics of the bulk material and the manner in which the material is handled. Con-

cerning the physical characteristics of the material, he notes that there is no convenient way for a designer to ascertain whether or not a material is dusty enough to warrant dust control measures. (The only guideline appears to be the "Standard Method of Test for 'Index of Dustiness' of Coal and Coke" approved by ASTM in 1941⁽¹²⁶⁾, a guideline which may or may not be applicable to various other substances.)

For enclosing dust sources, Morrison discusses four subject areas - the size of the enclosure, its ease of disassembly, access doors, and the installation of skirting and curtains at enclosure openings. He recommends that enclosures at transfer point be spacious to permit internal recirculation of dust-laden air and to suppress pressure surges caused by inflowing material and ingress of induced air. Specifically, it is said that enclosure heights be made not less than 2/3 the belt width and lengths from four to six times the belt width.

Designing the enclosure in removable sections for ease of maintenance is considered to be worthwhile. A note of caution is given that some form of gasketing material should be employed at jointing to reduce the risk of dust escaping. Hinged access doors, preferably self-closing by gravity and attached with quick-opening clamps, are reported to be useful and convenient to facilitate routine inspection and maintenance. Rubber skirting, attached to the enclosure sides by nut and bolt, or clamps, is recommended for along the enclosure sides between the lower enclosure edges and belt surfaces. Strips 1/2 in. thick by 9 in. wide with a No. 40 Durometer reading are noted as working very well. Further suggested is that the skirting be adjustable in height to allow balancing and fine turning of airflows.

A rubber curtain is suggested for the open end of the enclosure from which the conveyor exits. "The bottom edge should be cut to conform to the cross-sectional profile of the material conveyed on the belt. In addition, vertical slits 2 in. long and approximately 1/2 in. apart along the bottom edge of the curtain will regulate the size of the opening and prevent it from being torn loose when periodic surge loadings occur on the belt."

Morrison states that these recommendations only address the utilitarian aspects of dust control, aspects which have been developed by trial-and-error operating experience and which can be considered as conveniences which contribute to effective dust control. Appropriately, he reports that without proper exhaust volumes effective control is impossible. Consequently, he reviews the various popular "rule-of-thumb" methods for determining exhaust volumes given in Steel Mill Ventilation, ⁽¹²⁷⁾ the ACGIH Industrial Ventilation Manual, ⁽¹¹⁾ ANSI, ⁽¹¹⁸⁾ and others.

This review reveals wide disparities in recommended exhaust volumes for various belt speeds and material drop heights and it is observed that some recommended air volumes are exceedingly conservative while others are questionably low. Morrison concludes, therefore, that con-

sideration of only a few basic system parameters is insufficient to evaluate any given problem and that relationships must be established between all pertinent variables before reliable exhaust volumes can be calculated. Among the variables to be given consideration are included belt speed, material drop height, flow rate, lump size, density, and temperature, and enclosure opening dimensions.

Taking these various factors into consideration, the author attempts to develop a comprehensive approach. Using an equation by Hemeon, (113) and the results of his own study, he proposes an expression for determining the amount of induced (i.e., entrained) air by the action of the falling material. Similarly, he develops expressions for determining the amount of air displaced by the entering material and an expression for the amount of air required for proper control. The volume of air determined from addition of these three volumes, corrected for temperature differences by an empirical expression he developed, results in a total exhaust volume which he feels necessary for effective control.

Pring, Knudsen, and Dennis⁽¹²⁸⁾ support the statement that the criteria given most commonly in various sources may be considerably inaccurate. To illustrate their point, they note that the exhaust volume recommended for a 54-in. conveyor with a speed of 350 fpm is given as 2250 cfm by ANSI. For such a set-up, however, it was experimentally determined that 9000 cfm was necessary for effective control. "The reason for the discrepancy is, of course, that width and speed of conveyor have only indirect bearing on tonnage of material handled and no relationship to the height of fall onto the belt. Similar error is possible in the reference of exhaust volume to the area of openings in bins and enclosures."

Discussion

These authors make a very strong case that recommended control volumes in popular sources vary considerably and do not rigorously take into account important factors. The calculation methods Morrison suggests appear, on the surface, to be quite appropriate and much more apt to result in reliable and accurate exhaust volume determinations than those typically recommended. In many respects, however, what he has admirably accomplished must be considered to be more the qualitative conceptualization of a proper approach than the actual quantitative development of one which can be applied throughout industry. Reasons for this statement are given below.

While the paper repeatedly addresses the need for "effective control", there is no indication of what Morrison's definition is of this phrase. Since his paper was published in an issue of "Rock Products" and includes a picture of a belt conveyor transporting some type of crushed rock, one must question whether his method provides effective control for materials other than nuisance dusts.

For determining the amount of air entrained by falling material, he modifies the equation given by Hemeon for the turbulent-accelerating velocity case of falling spheres. His reason for doing so is that the

"equation yielded exhaust volumes which were considerably higher than field experience indicated were necessary." No justification is given other than "field experience lends empirical support to making the change." There appears to be a need, therefore, to review this subject area using all available data to produce correlations of confirmed validity. Reference 103, references 128 to 135 inclusive, and reference 113 are some of the information sources available on the subject.

As previously noted, Morrison's calculation procedure also includes a method for correcting for the temperature of the falling material. "Based on actual temperature measurements in the field, this author has derived an empirical expression which related the conveyed material temperature and the ambient air temperature to the temperature of the exhaust air." Since there is no other description of how this expression was arrived at, and the possibility exists that it does not apply to all substances and particle size distributions, there appears to be justification for questioning its overall applicability.

Conclusions and Recommendations

A number of subject areas, therefore, appear to require basic research to better define and quantify the factors which influence the achievement of effective control of air contaminants generated from belt conveyor transfer points. The resulting technology might also lead to better understanding and control of other processes in which materials fall from one plane to another (e.g. bag or drum dumping into a tank, bin loading, etc.).

The first question which enters a designer's mind when approaching such a problem must be whether the operation requires control at all. As noted by Morrison, the subject has been given little attention and no convenient method exists for such an a priori determination. While his point is well-taken that "only in a few instances would a truly representative sample of material be available for test prior to system design," the fact that he presumably is referring only to rock products leads to the conclusion that this may not generally be the case throughout industry. Hence, it is suggested that a study be conducted to develop a method whereby a sample substance can be subjected to the forces present in the bulk transfer and falling of solid substances. Ideally, measures such as shape-rugosity, hardness, apparent surface, dispersibility, etc. could be correlated in a manner which would allow indication of how much, if any, respirable dust might be produced from a given sequence of events, and whether the operation requires engineering control. Hopefully, in time, as the method proves itself, designers would have sufficient data to perform cost-benefit analyses on the various control measures available for use.

Such a program could be conducted in phases to help ensure its success before additional resources were committed. The first phase would essentially be a feasibility study to confirm the need for such a program, to critically review the available literature on the subject, to describe where and when in industry such a method might be useful,

and to define the approach to be taken to develop the method. Six man-months of effort over a time period of six months would probably be sufficient.

Actual development and trial of a test method could constitute the second and final stage of the program. Having chosen typical samples of materials, researchers would apply various test methods and correlate their results with actual test data. It is somewhat difficult to estimate the efforts required for such a program, but a guess would be 2 man-years over a 1 year period.

Determination of the amount of air entrained with a mass of falling material is, as noted, a subject which has been studied, but which seems to require a critical review to determine the merits of the various methods proposed in the literature. Such a review and analysis could most likely be accomplished with 3 man-months effort over a time span of 4 months and could be expected to point out which method is "best" and what further study, if any, appears warranted. A similar study in effort and scope could be accomplished for developing methods for temperature correction.

The volume of air which must be withdrawn for "control" purposes from an enclosure or container into which a toxic substance is falling might also be given consideration for study. While an exhaust volume of X cfm per sq ft of open area in an enclosure may be capable of reducing the amount of dust released, it may provide an unnecessary degree of control for nuisance dusts while providing far too little control for highly toxic substances.

Once these separate subject areas had been adequately studied, the final task would be to join the various calculation procedures together into one single procedure, and to confirm the validity of the method using actual field data. An 8 man-month effort conducted over a time span of 6 months would probably be sufficient to collect data from transfer points and to compare them to the results obtained from the 3 parts of the overall procedure studied. To determine the amount of "control" air necessary, the conveyor speed at one site might be varied and dust counts taken or a number of similar operations which involve different speeds might be investigated. These air sampling data could hopefully be correlated with the various belt widths, speeds, and types of materials involved and criteria developed for effective control of materials of varying physical and toxicological characteristics.

Belt Conveyor Straight Runs

Various sources contain design criteria for enclosing and ventilating the length of a belt conveyor and for a belt wiper to clean off the belt before its return run. The first of these is to control dusting off the top of the load; the second, to prevent dusting off the return belt.

The controls recommended by the ACGIH manual for the load include a full enclosure exhausted at least every 30 feet with a tapered exhaust connection drawing 350 cfm per ft of belt width. It is not immediately apparent how these figures were arrived at, but if the enclosure was well designed, one would expect that an adequate degree of control could be achieved with this set-up. Buffington notes that slider-bed belt conveyors, similar to other belt conveyors except that idlers are not used to support the belt, can be employed for handling light loads where a dust-tight enclosure is necessary. For handling asbestos on a belt conveyor, Goldfield and Brandt⁽¹³⁶⁾ describe a full and ventilated enclosure which goes well beyond the types of enclosures normally found. It is essentially a complete metal box about all parts of the machinery.

The mining industry and others utilize water and other sprays on material being transported to reduce dust generation. This control would also tend to reduce contaminants from most operations involving dusty substances and "wetting" is often an adequate alternative to ventilation.

A belt wiper design, presented by the ACGIH manual, is essentially a scraper combined with a slot hood against the bottom of the belt. With a recommended exhaust volume of 200 cfm per ft of belt width and a slot velocity of 2000 fpm, it appears to be adequate to remove any dust which might adhere to the belt. Indeed, this combination of a scraper and a high velocity hood appears to be substantially better than just the provision of rotating brushes or a scraper. However, Goldfield and Brandt report that "in spite of all cleaning equipment on the market, the return belt often carries dust to the idlers. In extreme cases, it is necessary to enclose the return belt with a complete leak-tight enclosure and to clean that enclosure by means of scraper conveyors."

Other Types of Conveyors (123, 137)

The belt conveyor is but one of many types available to industry. Others include the pan, drag chain, en masse, zipper, flight, screw, vibrating, pivoted bucket carrier and pneumatic types. Little information appears to be available in the literature concerning whether engineering controls are required to prevent exposures when these types are used. That information which could be found, and that which could be inferred, are summarized in the following.

Drag Conveyors

Used frequently for handling hot clinkers, ashes, coal, sawdust and similar materials, this conveyor is made of a special wide chain which is dragged through a hard trough made of white iron, steel, or concrete. Illustrations in the literature indicate that the trough could probably be covered to restrict dusting problems during operation. Since the chain returns to its starting point over rollers above the trough, any dust sticking to it may be shaken loose. As with other conveying mechanisms, dust can also be assumed to be generated at loading and discharge points.

En Masse Conveyors

The en masse or continuous-flow conveyor moves material as a single mass through a tube by using stirrup-shaped or solid flights. It is especially useful with non-abrasive materials that must be handled gently and has numerous other advantages for use. The primary disadvantage appears to be that it requires more power for a given load than some other types. Buffington reports that they can be sealed to prevent contamination and to contain fumes, "an important factor in solvent extraction processes." This type of system is noted as being one of the two mechanical types available which does not require special considerations when materials are handled which dust excessively, the other mechanical type being the screw conveyor.

Flight Conveyors

Working well with sticky or abrasive solids, flight conveyors are simple in design and slow moving. They consist of one or two strands of chain that drag wood, steel, or plastic flights through a trough. The returning flights travel above the trough in the opposite direction and material adhering to them may possibly be shaken loose. Loading and discharge points appear to be of concern as with other conveyors which are gravity-fed or discharged.

Pan Conveyors

A pan conveyor is often used to carry large, heavy lumps and is frequently found in metallurgical plants feeding raw ore to a crusher. Consisting of metal pans carried between two rows of chains, it may be used to carry molten glass while it cools. Examination of illustrations of this type show that the pans return in an upside-down fashion back to their starting point. Any material which sticks to the pans can thus be expected to be shaken off during the return trip. Furthermore, since they are similar to belt conveyors, loading and discharge points may need controls when dusty substances are handled.

Pneumatic Conveyors

Pneumatic conveyors are, in simple terms, a pipeline through which materials are moved by means of a vacuum, under positive pressure, or by a combination of both. Since they are completely enclosed, product contamination, material loss and dust emission are reduced or eliminated. Their prime use is to convey dry, granular or powdered materials via pipelines to remote plant areas that would be hard to reach economically with mechanical conveyors. An article in Food Engineering⁽¹³⁸⁾ demonstrates how the use of closed pneumatic conveyor systems has eliminated dust problems in the filling of hoppers above filling machines for food products.

Screw Conveyors

Screw conveyors can be used to convey, feed, mix, agitate, dig and blend. They essentially consist of a long screw which, by revolving in a trough or tube, propels the material forward. According to Buffington, they can be effectively sealed to keep in dust and fumes⁽⁶⁾ and keep out moisture and contaminants. An article previously cited reported that the use of these conveyors in a pharmaceutical plant allowed strict sanitary requirements to be met.

Vibratory Conveyors

Vibratory or oscillating conveyors propel the load forward by imparting forces generated from vibrating the supporting system at its natural frequency. The equipment may be of the open trough design or fully enclosed. Standard units have capacities up to 500 tons/hr and can handle materials at temperatures up to 250°F. They are versatile in that they can be used with small sand-like particles or very large pieces such as castings.

Pivoted Bucket Carriers

This and the "Peck" carrier operate in the same manner, and the unit is much like a bucket elevator except that the buckets pivot so they can travel horizontally until a discharge point is reached and they are turned over. The points at which they are loaded or discharged appear to have the potential of generating dust. Each bucket is, after all, dumped from some height into a chute opening or bin.

Discussion

In our previous program to develop recommended ventilation guidelines, an attempt was made to extrapolate the control measures recommended for belt conveyors to conveyors of other types. At transfer points, where dusty material falls from one plane to another, it can be expected that the forces and airflows generated will produce airborne dust regardless of the specific type of conveying mechanism used. During straight runs of non-enclosing conveyors, it can be considered that dusting off the top of the load or dust falling from the return side would add to the problem. Thus, it appeared that providing examples of enclosures and recommended exhaust volumes, based on analogy to belt conveyor controls, would be useful. Reviewers of the resulting guideline, however, strongly objected to this extrapolation and it was therefore deleted from the final version. The reasoning was that the guidelines upon which it was based were developed solely for belt conveyors and were not proper for direct use with other conveyor types. Having pointed out the disadvantages of using the control measures given in popular sources, this conclusion can now be fully agreed with.

Conclusions and Recommendations

The first of any efforts directed towards normally unenclosed conveyors other than belt conveyors should be to determine if indeed the use of these mechanisms in some industries results in excessive, or hard to control, concentrations of airborne contaminants. A limited survey of this type could probably be accomplished with 5 man-months effort over a time span of 8 months. Its results would characterize the types of substances generally handled by each type of conveyor, the controls used to reduce exposures, and the airborne concentrations evident. If it were found that there was a problem requiring further investigation, the following suggested efforts would be warranted.

In the discussion above for belt conveyor transfer points a program was suggested for developing a comprehensive approach for calculating accurate exhaust volume requirements. If and when such a program were to be conducted, it could be expected that modest additional effort would be required to modify the procedure for use with other types of mechanisms. These modifications would probably involve only the part of the procedure for estimating control volumes, and could probably be simply and accurately determined from theoretical considerations or from the data obtained from the belt conveyor program. An effort of 1 man-month over a time span of 2 months would probably suffice if field verification were not felt necessary.

The ACGIH Ventilation Manual, as noted for belt conveyors, also gives recommended criteria for ventilating straight runs of belts and for the design of belt wipers, the former of these to control dusting off the top of the load and the latter for dust from the return belt. To some extent, these phenomena may possibly also occur with other mechanisms depending upon the material handled and the transport speed. Another area of interest might be the determination of how analogous controls may be developed for these other types of conveyors.

Bin Filling

Literature Review

For mechanical loading of bins, the ACGIH suggests that the loading point be enclosed and that an exhaust connection drawing 200 cfm per sq ft of all open areas be installed either directly over the loading point or at a location on the top of the bin remote from the loading point. For hoppers which are manually loaded, presumably into bins, it recommends a three-sided booth over the hopper with an exhaust connection at the rear which draws 150 cfm per sq ft of face area. Specifically for "grain" elevators, feed mills, (and) flour mills", it recommends 550 cfm per bin.

ANSI and Steel Mill Ventilation recommend a capture or control velocity of 150-200 fpm through openings in the enclosure and an exhaust

rate of 0.5 cfm per cubic foot of bin volume. The latter adds that these velocities are based on general velocities in material handling systems and that a more detailed analysis requires use of correlations which take into account material flow rate, size, the free fall trajectory distance, and the enclosure opening area.

Kruse and Bianconi,⁽¹³⁵⁾ Pring, Knudsen and Dennis⁽¹²⁸⁾ and others report that such recommendations as are in the ACGIH manual and ANSI are largely empirical and based on trial-and-error methods or on the personal experience of a designer.

Discussion

It has repeatedly been pointed out in the above that operations characterized by the falling of a material from one plane to a lower one involve effects which are not taken into consideration in many of the guidelines found in popular sources. This also appears to be entirely true for bin filling operations.

Conclusions and Recommendations

If the program suggested for conveyor transfer point controls is conducted, the resulting technology should be utilized to develop a method for accurate determination of required exhaust volumes for bin filling operations.

Bucket Elevators and Chutes

Many of the same sources cited above, and below, recommend controls for operations involving bucket elevators and chutes. As for belt conveyor transfer points and other operations discussed in this section, it appears that given recommendations are based on personal experience and trial-and-error research on a limited number of operations. Thus, detailed reasoning is not presented here for why the results of research conducted for such transfer points should be applied to these devices also, but it follows from the preceding that it should be.

4.8.3 BAG AND DRUM FILLING

Bag Filling

The bagging of powdered materials such as plastic resins, paint pigments, pesticides, cement, and the like is generally accompanied by the generation of airborne dusts. This occurs due to the displacement of air from the bag, spillage, and motions of the bagging machine and the worker. When the dust is toxic, the potential exists for the operation to adversely affect the health of workers.

In a limited survey ADL personnel recently conducted in a chemical plant, attention was given to the actions involved in a simple bag

filling operation. The steps of the operations were: (1) the operator secured a bag on the filling tube; (2) a measured amount of the powder was dumped into the bag from a hopper; (3) the bag was removed from the filling tube and placed onto a small scale; (4) a scoop and a nearby drum of the product were used to bring the weight of the bag into specification; (5) the operator closed the flaps of the paper bag; (6) he lifted it onto a pallet; and (7) he "patted" it down.

The filling of the bag was conducted within a three-sided enclosure with an exhaust takeoff at the top. Nevertheless, the operation produced excessive contaminant concentrations because of the necessity of steps (3) thru (7). The "plopping" down of the bag on the scale, the pouring in of a partial scoop of powder, and the placement of the bag on the pallet all appeared to release some amount of dust to the atmosphere at locations obviously uncontrolled by the enclosure. The floor was covered with the highly toxic substance and the bags were lightly covered with a layer of dust. Crossdrafts produced by a nearby open garage door served to stir up the spilled contaminant during gusts. These observations led to the conclusion that it is not the actual bag filling operation which is often difficult to control as it is the ancillary actions required of the operator. Recognizing this fact, the management of the company themselves suggested the need for machinery which automatically and accurately fills and seals the bag and delivers it to a pallet loading station. To further reduce the amount of the chemical which may spill from the bag, and thereby cause exposure problems in subsequent warehousing and transport operations, it was decided to place a plastic liner within the paper bag, a liner which could be securely heat-sealed.

Literature Review

Hama⁽¹³⁹⁾ studied the control of dust from bagging operations in 1948, and determined "that bagging machine workers at uncontrolled operations are exposed to concentrations of dust in the magnitude of 100 million to 1000 million particles of dust per cubic foot of air." Discussing the various local exhaust hood configurations practical for use, he found that side draft hoods and slots and the double-canopy type (where the air is exhausted in the concentric space between the hood and the bag-filling tube of the machine) are not capable of completely controlling the dust. "From a number of dust counts taken on various types of local exhaust hoods," he therefore concluded that the best control is achieved by a simple three-sided booth enclosure. Features of his recommended design for such a hood included a plexiglass window to reduce the open face area and a hinged plate edging on the front edge of the floor to confine spilled material within the booth.

For bagging machines located where high-velocity crossdrafts are present, Hama recommends face velocities from 200 to 250 fpm. Under calmer conditions, he remarks that 150 to 200 fpm will be adequate. Since the area of the greatest dust release is near the top of the

booth, he further recommends that the branch exhaust duct be connected to the top of the hood. As an example of the degree of control which can be achieved, he illustrates an operation which, before ventilation was installed, produced dust counts of 173 to 182 million particles per cubic foot of air, and after installation, produced breathing zone concentrations of the order of 3.5 mppcf. The airflow distribution in this booth was: top third of face, 250 fpm; center of face opening, 200 fpm; bottom third of face opening, 150 fpm.

The ACGIH manual contains two exhaust system designs for such operations, one for "bag filling" and another for a "bag tube packer." The first design shows a bin which feeds into a funnel to which the bag is securely attached. The open area between the top of the funnel and the bottom of the bin is pointed out as being the principal dust source and is partially enclosed with a hood. The exhaust volumes recommended are 400-500 cfm for "non-toxic dust" and 1000-1500 cfm for "toxic dust". The maximum recommended face velocity for the open bottom portion of the hood is given as 500 fpm.

The exhaust system design for the "bag tube packer" includes a number of exhaust hoods. One hood is installed on the feed hopper and has a recommended exhaust volume of 500 cfm. Another is installed at the side of a spill hopper under the machine and has a recommended exhaust volume of 950 cfm. Others appear to be installed over the individual filling tubes and have recommended exhaust volumes of 500 cfm each.

Constance⁽¹¹²⁾ recommends 130 to 150 scfm/sq ft of hood face opening for a "hooded bag or drum filler from pulverizer", 125 scfm/sq ft of face opening for a "hood enclosure for bag packing", 450 to 500 scfm/sq ft of pouring slot for "bag filling", and 125 scfm/sq ft of face area for a "hood over bag packing from belt packer".

Kane⁽¹⁴⁰⁾ reports that New York Code 34 for silica dust in stone crushing operations recommends a booth or enclosure for bagging machines (with a spillage hopper) and exhaust requirements as follows: Paper bag - 100 cfm/sq ft open area; Cloth bags - 200 cfm/sq ft open area.

ANSI gives essentially the same recommendations reported by Kane. For pulverized sand, however, it recommends 400 fpm at the point of origin.

Burke⁽¹⁴¹⁾ describes the various bag filling machinery available to the chemical industry, the accuracy of various systems for weighing out substances and the economics involved in choosing the correct set-up for a particular operation. An interesting observation that results from a review of his paper is that the simpler the bag filling and weighing operations are, the more prone they are for resulting in bags of product which are further from a desired weight specification. A look at a graph he gives for savings per year vs. bags filled per hr

indicates that the savings potential from using machinery of greater accuracy can in the course of a few years justify the initial cost of installation of better machinery. Thus, one gets the impression that a manual weight checking step and other actions can be eliminated in such operations with advantages both in reducing exposures and in increasing profits.

Discussion

Hama indicates he could control dust counts to 3.5 mppcf using the enclosure and exhaust takeoff configuration he recommends. Given the present exposure limit of 50 mppcf for total nuisance dust, this must be considered to be more than adequate control for such substances. For highly toxic substances, however, this degree of control must be considered inadequate. For the bag filling operation we observed, it was estimated that 100,000 particles of a fine dust (<2 microns) would approximate the TLV. The other guidelines, given only as examples of many which can be found, obviously vary widely in their recommendations. One must therefore wonder how and when they are applicable, to what types of substances they apply, and whether they provide adequate control if installed.

Conclusions and Recommendations

The actions involved in bag filling operations are simple to comprehend and the sources of air contaminants easy to characterize. Nevertheless, there appears to be some degree of confusion in the literature as to how such operations should be controlled. It is therefore advised that a program be conducted to classify the types of bags and bagging machinery currently available and the actions required of workers, and to determine how best each of these operations may be controlled for substances of various physical and toxicological characteristics. The study should then devote some efforts to better quantify the manpower and product savings advantages and disadvantages of utilization of inherently "cleaner" machinery. This type of limited field survey and information collection and analysis effort could probably be accomplished with 8 man-months effort over a time span of 6 months.

Drum Filling

Just as the filling of bags can generate air contaminants, so can the filling of drums. The problem does not appear to be one of similar severity, however, since numerous references to the hazard of the operation do not appear in the literature as they do for bag filling.

Numerous recommendations exist in popular sources as to how these operations can be controlled. The ACGIH manual, for example, gives four possible hood configurations and attendant suggested exhaust volumes. Two of these appear in Hemeon. At least one of these, a full enclosure with a suggested exhaust volume of 150 cfm per sq ft of open area, can

be considered to be adequate to control most toxic substances.

Thus, while some methods may be better than others depending upon the toxicity and physical characteristics of the substance, specific research for this operation does not appear to be warranted at this time. However, if the program suggested for belt conveyor transfer points is conducted, it would be expected that the technology would then exist to allow more accurate determinations of required exhaust volumes for effective control. As for that operation, it would be expected that the rate of flow, particle size, material density, material temperature, fall height, and other factors would influence the determination of the amount of air which must be removed for effective control.

4.8.4 STORAGE AND TRANSPORTATION OF PACKAGED MATERIALS

Package Integrity

One source of toxic chemicals released into the industrial environment is from broken bags, a sight which can be seen in almost every warehouse, boxcar, loading platform, or internal plant area where large numbers of bags are stored or handled. For many substances, a broken bag doesn't present a serious hazard to workers. For some, however, those which are highly toxic, it may. When such bags are transported on fast-moving fork-lift trucks, it is likely that some powder released will be dispersed into the air. When they leave a "pile" of substance on the floor, drafts from open loading doors and airflows caused by mobile machinery may do the same.

Uncles⁽¹⁴²⁾ writes that some breakage and product loss must be expected in bag shipments, that the odd rip or tear or puncture or snag is inevitable, and a damage rate of 0.5% (1 out of 200) is not considered bad shipping experience. He notes that it may be good economics to attempt to reduce this figure by adding to the container cost, but that it frequently turns out that the cause of the damage would have the same effect regardless of the number of plies or weight of bag used. Also noted by this author is that the Department of Transportation limits the types of containers which may be used for hazardous materials to reduce the probability of unintentional release.

It is most certain that the Department of Transportation has expended considerable effort in ensuring that interstate transport of hazardous commodities does not take place using containers which can easily rupture and cause an immediate danger to the public. However, it is also certain that many highly toxic substances are transported intrastate, or are quite properly transported interstate in paper or plastic bags, probably the most fragile of the types of containers in which such chemicals are handled in moderate quantities.

There is some cause to consider whether NIOSH should review DOT regulations as to how they affect the probability of exposures occurring

in the workplace. Such a study would be concerned with determining the physical and toxicological characteristics of toxic substances which might lead to hazards in the workplace, would compare these characteristics to DOT classifications for hazardous commodities, and would suggest what changes, if any, might be suggested to DOT. Since suggested changes would need to be fully justified and well-documented, such a program might require 2 man-years of effort over a time span of 1 year.

Emptying of Bags and Drums

For a number of the industries investigated in this report, there has been quoted at least one authority who flatly states or implies that the dumping of a fine powder into a tank or a hopper, or the scooping of an amount of a powder into some type of receptacle, generates dust, sometimes much of it, into the breathing zones of workers. In the following, we therefore review and discuss various controls recommended for such operations in the literature.

Literature Review

Owen⁽¹⁴³⁾ reports on how fine, toxic dust in the "difficult-to-capture" 0.10 to 10 micron range was controlled. "At two of the 200-gal (paint) mixing tanks, when 50-lb bags of pigment powder were added, bursts of dust resulted from dumping the bags. This problem was solved by designing the collection hoods for these tanks as 'flip tops', which raise to permit adding the sacks of pigment, and then close until the dust is taken into the (exhaust) system."

Stern and Horowitz⁽⁴⁰⁾ graphically describe the hazards of these operations. Not only do they report that the dumping produces a "puff" of dust, but also, that excessive dust is generated when bags are shaken or struck against the side of a mixer or mill or an "empty" bag is tossed aside. They recommend covers which are hinged for access for open top mixers and specially designed hoods at mill loading spouts. To allow bag or drum dumping into the mixers, they suggest that a hole be cut in the front of the cover and that vertical side and rear sheets, extending up at least a foot above the opening, be installed around the opening. A downward air velocity of 200 fpm is recommended through the opening from an exhaust connection at the rear of the mixer cover. To avoid the possibility of sucking out any raw materials from the mixer, "a bug-a-boo in the minds of many executives", a long converging connection upward from the rear cover is suggested. A lateral draft hood over loading openings is recommended as an alternative to the above. The exhaust volume recommended is 1000-1500 cfm.

To avoid scooping of small amounts of highly toxic substances, Stern and Horowitz suggest that they either be weighed, mixed and dispersed in a vehicle in the laboratory (under a hood if necessary) or that the containers of the substances and the scale be enclosed in an open front booth.

Goss and Ross⁽¹⁴⁴⁾ investigated the hazards of operations involving the handling of lead compounds. Finding that the health hazard was significant, they instituted new procedures in the plant they were studying, procedures which were successful. To summarize, they required that all transfer of dusty materials be restricted to a single exhausted enclosure. Here, dusty materials were either processed into non-dusty pastes by mixing with a liquid or, when this was not practical, the materials were weighed into plastic bags which were hermetically sealed before being brought into the factory proper. Since they were in a plant processing polyvinyl chloride resin, the plastic bags were just thrown by the operator into mixers or blenders, where eventually the bag dissolved in the mix.

Hemeon reports that dust is generated from two sources when a scoop or shovel is used; at the point the scoop or shovel is filled, and at the point where it is discharged into a receptacle. For containers and receptacles not permanently placed at one location, he recommends the use of flexible metal hoses which can be conveniently placed over each container. For charging of open mixers, he illustrates a slot type exhaust hood along one top edge with an exhaust volume selected on the basis of 75 to 100 cfm per sq ft of top area. He notes that a tightly fitting cover can obviate the need for any exhaust during mixing.

The ACGIH manual addresses manual loading of hoppers. The design shown is essentially an open front booth with a rear exhaust connection. The exhaust volume recommended is 150 cfm per sq ft of face area.

Steel Mill Ventilation recommends a capture or control velocity of 150-200 fpm for openings in bin and hopper enclosures and notes that these velocities are based on general averages in material handling systems. ANSI simply recommends a 150 fpm control velocity through manholes or inspection openings of closed tanks.

An advertisement in Iron Age⁽¹⁴⁵⁾ illustrates how dust concentrations can be controlled or reduced in many operations by using substances in pellet form. Since phenolic dust was a problem for molders, General Electric's Plastic Department developed a new barrel replacement for molding machines which could handle the substances in this form. They note that "there's no need for separate molding areas or special maintenance and ventilation." Whether they realize it or not, they make a pun in stating their "marketplace looks almost exhaustless."

In one situation, one of our staff suggested the use of a flexible, tubular screw conveyor to transfer the contents of drums of a very fine powder into a tank. One end of the tube was to be placed through a hole in a typical drum cover. The other end was to be placed through an opening in the leaky, but essentially closed top of the tank and down to a point just above the liquid surface. This solution had many advantages.

The workers liked the idea because they would not have to lift the heavy drums up to dump them and were concerned about the excessive dust usually generated. Management expressed interest because clean-up of the fine powder was difficult but necessary on a frequent basis. Furthermore, the conveyor was relatively inexpensive and had a flowrate which would not slow production when all factors were given consideration. Unfortunately, it was never determined whether the idea was implemented. It can only be assumed that it would be useful since the drum would not have to be violently agitated, a tight drum cover on a drum from which material was being drawn would cause an induced airflow into the drum through any openings (e.g. the opening the tube passed through), the tube was obviously sealed to its other end, the flowrate was slower and more uniform, and the drop height of the substance from the discharge end would be greatly reduced.

The extreme toxicity of asbestos fibers has required that measures be developed for the opening and emptying of bags in a manner which does not result in excessive exposures. Goldfield and Brandt illustrate an enclosed and ventilated bag opening station which even has provision for pushing the empty bag into another clean bag for subsequent disposal. The discharged asbestos falls into a hopper which is connected to a screw feed, chute, belt conveyor, etc. Hills⁽¹⁴⁶⁾ describes a similar station and includes a picture of one in operation.

Conclusions and Recommendations

A small-scale effort to more fully review these material handling procedures and the controls available to industries which utilize packaged solids might be warranted. The researchers would survey such industries as the paint, plastics and rubber industry to observe the controls commonly utilized, to catalog the various methods found to be useful, and to produce a report which describes the work practices and engineering controls available for use (along with their individual advantages and disadvantages). If the research recommended in the "conveyor belt transfer" part of this section were conducted, the relationships developed for entrained air, etc. might be applied to these operations to improve upon the determination of proper exhaust volumes where ventilation is to be used as the control. A 6 man-months effort over a time span of 5-7 months would most likely be adequate.

4.8.5 OTHER OPERATIONS

Pouring Stations For Liquids

Wherever "volatile" substances are poured from a spout into a container, some release of contaminants can be expected. In the foundry, fumes are released when molten metal is poured into ladles or molds. In the paint and other coatings industries, solvents may be released when the contents of mills or mixers are poured into portable change cans. While ladles and change cans can be covered while being moved

through a workplace, they must of necessity be open at the points they are filled or discharged.

Pouring stations for molten metals are a subject covered by the ACGIH and in the American Foundrymen's Society manual of "Foundry Environmental Control". The hood designs and recommended capture or control velocities of about 200 fpm in these sources appear to be fully adequate to capture any fumes generated. The various designs given for side-draft hoods, enclosures, and open hoods can also be expected to be adequate for controlling vapors evolved from other liquids being poured. Thus, while a study to develop a method to calculate accurate required exhaust volumes based on the projected area of the stream, its fall height, volatility, toxicity, etc. might be somewhat useful, the benefits of such research does not appear to warrant expenditures of time or funds.

4.8.6 OVERALL DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

We have identified and described the engineering controls commonly utilized within industry to reduce exposures to airborne contaminants generated during material handling operations and processes. The overall conclusion arrived at from this review is that, while numerous recommended ventilatory controls exist in the literature, many of these are contradictory, are not based on proven scientific principles, and may easily lead to inadequate control of operations. It is not to be implied that these guidelines are without merit. In the hands of knowledgeable practitioners, they are highly useful tools and may be modified as necessary to fit a particular situation. There is concern, however, that when these guidelines are rigorously applied by the uninitiated, they could unknowingly result in ineffective control.

There appears to be considerable merit in the suggestions to investigate, identify and confirm those principles and factors which influence operations involving falling toxic substances. Such programs would firmly base calculation procedures upon proven principles and would give them a much higher probability of resulting in adequate control. For the expert in the field, they would also be useful. When faced with a novel situation, estimates of what specific controls are necessary would tend to be more accurate. Control systems could be designed, constructed and installed simultaneously with plants themselves, and the need for trial-and-error "patchwork" modifications would be reduced or eliminated. A priori cost-benefit analyses could be more accurately be performed to compare different methods known to be satisfactory.

For both bag filling and container emptying operations, specific programs were recommended to survey the state-of-the-art of controls and report on them. Given the number of literature sources which illustrate the hazards of these operations, the amount of attention they have received for controls seems to be insufficient. Indeed,

there was rarely an author reviewing the health hazards of an industry which did not state that the bag filling and mixing and compounding areas were those of highest contaminant concentration.

The review of DOT shipping regulations recommended is of somewhat more uncertain merit. It is presented as an idea to be further discussed and investigated before action is taken. The idea essentially evolved from observations in two plants which handled large numbers of bags; one which filled, stored and shipped them, and the other which received, stored and used their contents. In both cases, spillage from broken or leaking bags was troublesome. Since bag shipments of these materials were industry practice and completely proper under current DOT regulations, it was rather impractical to suggest a change in container type to either management.

A review of the various descriptions and discussions above indicates that there are numerous ways to control each type of operation, and it is evident that each has its own particular advantages and disadvantages. Popular sources of recommended control measures are usually very brief and describe but one way to control an exposure. Thus, as a final recommendation for this subject, it is suggested that NIOSH consider the publication of a manual concerning the uses of engineering controls for materials handling operations. A manual of this sort could serve a useful function. It would describe the hazards of various operations, the types of equipment typically used, and the various control measures which are applicable. For each of the controls, for which specific design or other criteria would be given, it could discuss advantages and disadvantages, degree of control provided, operating costs involved, etc. Periodic updates of the manual would keep the publication "state-of-the-art". Its initial preparation would probably take 2 man-years effort over a time span of 1 year.

4.9 NON-SPRAY APPLICATION OF VOLATILE MATERIALS

Introduction

Whenever a substance containing volatile constituents is applied to a surface in an industrial environment, there is obviously potential for any vapors evolved to enter the breathing zones of workers. If the volatiles evaporate at a sufficient rate and/or the particular operation is such that workers must remain in the immediate vicinity of the "wet" coating, these vapors may result in excessive exposures.

The specific types of industrial operations and situations in which such exposures can occur are many and varied in nature. Off-hand, one might consider the plight of painters working in poorly ventilated and/or enclosed spaces, workers at benches manually applying adhesives to various materials, and even workers who might enter a room painted or coated with some substance sometime previously, a substance which is still evolving volatile constituents at some finite rate. In this latter case, it does not really matter whether the coating was applied by spray or other technique.

In practice, according to Riley,⁽¹⁴⁸⁾ the nature of the hazard and the greatest likely exposure may be determined in three ways. The first of these involves observation of an actual application in the field or in a test room. The second involves an assumption of an application rate and an estimation of the maximum concentration in air from the evaporation of all volatile materials. Finally, one may devise a scale model of the process to simulate severe plant conditions.

Of the first technique above, Riley points out that it presents some economic and logistic problems and develops information which lacks definition, since the conditions are hard to control or define. The second is noted as being relatively simple but as providing an unrealistic evaluation of the hazard. The third approach is noted as being open to some criticism but having the advantage of largely avoiding the limitations of the others.

The various approaches outlined by Riley appear to be most applicable for determining the rate of general ventilation necessary in an enclosed area to maintain average concentrations at or below exposure limits. However, where workers in some sort of production line continuously apply volatile coatings, localized concentrations of contaminants may greatly exceed average concentrations. In the following, therefore, various methods are reviewed for specifying not only general ventilation criteria but also local exhaust ones.

Literature Review

Riley reports upon a laboratory model designed to simulate a small, somewhat poorly ventilated room and to develop quantitative information concerning the rate of evaporation and the probable exposure resulting when the ceiling and four walls are painted rapidly with a coating under investigation. Use of the model is claimed to allow determination of whether the coating contains ingredients likely to create a health hazard from a proposed application, and of the nature of the hazard. It also is said to be capable of defining the greatest exposure likely to be encountered in actual use and of allowing comparison with other products or materials available.

The experimental apparatus essentially consisted of a 1-foot cube with a slot inlet and a sampling port which exhausted the enclosure at a fixed rate of 0.1 cfm. To approximate the conditions to be expected when a 10 x 10 x 10 foot room, ventilated at a rate of 100 cfm, was rapidly coated on 5 of its 6 sides, one-half of one side of the model cube was coated with the test material before the test commenced. Results of the test procedure included concentration in the enclosure versus time data for the various components in the coating material.

Riley acknowledges that, while the basic principles of his approach can be applied to many industrial processes, his model was designed for a specific purpose and, as constructed, provides information applicable only to his specific application. He notes that "care should be used in extrapolating from these conditions to different temperatures and different ventilation rates and patterns."

In considering the application of his experimental data to the estimation of the probable exposure, Riley comes to the conclusion that the rate of release of volatile components from the coating would be a more useful value than the concentration in the box. He notes that for plant conditions significantly different from the test model, these data could be used to compute probable concentrations. Using relationships between the various data available, he therefore presents a method for determining the specific evaporation rate (weight per unit area per unit time) from the coating from the available data.

Boyle and Novak⁽¹¹⁴⁾ also address the subject of predicting ventilation requirements for coating materials. Though they are primarily concerned with determining the evolution rate of substances evolved in curing ovens, the test method they describe also results in curves of specific evolution rate versus time at some given temperature and air humidity.

The ACGIH Industrial Ventilation Manual⁽¹¹⁾ recommends the second type of approach discussed by Riley, i.e. the assumption of an application rate, an estimation of the maximum concentration in air from the evaporation of all volatile materials, and the calculation of the necessary amount of dilution air required from dilution formulae presented. It is noted that factual data are needed on the rate of vapor generation or on the rate of liquid evaporation, and that such data "can be obtained from the plant if they keep any type of adequate records on material consumption."

The ACGIH lists four limiting factors for the use of dilution ventilation. These are: (1) the quantity of contaminant generated must be not too great or air volume necessary for dilution will be impractical; (2) workers must be far enough away from contaminant evolution, or evolution of contaminant must be in sufficiently low concentrations so that workers will not have an exposure in excess of the established TLV value; (3) the toxicity of the contaminant must be low; and (4) the evolution of contaminants must be reasonably uniform. To ensure adequate control, a multi-purpose safety factor K is described for application to the calculated air volume. It is said that K should vary from 3 to 10 depending upon the toxicity of the material, the evolution rate of contaminant and the effectiveness of the ventilation. No attempt is made, not even a qualitative one, to describe the conditions under which various K values are appropriate.

Hemeon⁽¹¹³⁾ contains a detailed chapter on the application of general ventilation. Equations are derived which allow calculations of the rate of concentration build-up when contaminant is injected into a ventilated space and the rate of decrease of concentration with time when some fixed rate of ventilation is applied to a space initially charged with contaminant. Addressing the subject of general ventilation for industrial solvents, Hemeon gives an equation for estimating the amount of dilution air necessary which is quite similar to the one given by the ACGIH. Instead of a K factor, however, he uses a contaminant concentration somewhat less than the TLV.

Hemeon explicitly states that it is necessary to explore the question of local concentrations caused by work requiring the worker to maintain a position close to a source of solvent vapor. It is noted that breathing zone samples during normal working operations would determine whether concentrations were excessive or not, "but in the planning of new operations it would be helpful to have a method for estimating the need for ventilation measures supplementary to the general ventilation." He then presents various calculation methods which allow estimation of breathing zone concentrations as a function of the nature of the vapor source, the working distance, and the rate of contaminant evolution.

To provide local control of operations which expose workers to excessive contaminant concentrations, Hemeon discusses the design and location of booths, slot hoods, and canopy hoods. Though use of a canopy hood in a configuration which causes vapors to be drawn past the breathing level is generally reported to be an undesirable control method, Hemeon demonstrates that if the exhaust volume is specified correctly, the breathing zone concentrations can be sufficiently diluted due to entrained fresh air. For operations involving the manual application of coatings to walls or floors, he illustrates the use of portable exhaust plenum chambers with slots. Both of these latter control measures are designed to collect vapors from their source, thereby reducing concentrations in breathing zones, and then to exhaust the vapors, together with entrained air, back into the work place where general ventilation can remove them.

ANSI, (118) in demonstrating the proper location for manufacturing hoods, generally illustrates a "cementing table" having lateral exhaust slots along two sides. Detailed design data for such a table are not presented however.

Kingsley (21) describes the hazards involved in manual "wet layup" operations involving uncured epoxy resins. To reduce the incidence of sensitization among workers, he designed an area for handling these substances which resembled a large water-wash booth. The area was 15 feet deep from the water tank to the outer edge of the hood. Total exhaust volume was 24,000 cfm. For some work, a downdraft table with a rotating top was used. A feature of the unit was that air could be drawn across the work when a panel was removed from the front of a plenum to one side of the table. Baffles ensured that the down-draft flow was not stopped.

Discussion and Conclusions

This entire subject area is a complicated one entailing numerous factors to be given consideration, especially when there is a desire to determine the controls necessary in the planning stage of new operations. From the above, it appears that Hemeon approaches the overall subject most completely. Not only does he provide the means for determining appropriate general ventilation rates, but he is also concerned with the means for dispersing any localized areas of high concentration.

Regardless of the specific design methods given in the literature, however, one of the basic parameters which appears to require better definition is the evaporation rate of volatile constituents out of an applied coating. While estimates based upon the total volatiles within the coating material lead to conservative estimates, there does appear to be a need for developing a more precise method, one which also provides data useful for other purposes, i.e. the comparison of the hazards of different coatings when applied under similar circumstances.

Overall, it appears that three aspects of the problem might be given closer attention. Such attention would result in the following:

1. A method of comparing the exposure hazards of various coatings for allowing selection of that coating which presents the least overall hazard,
2. A method of determining how long it will take under given environmental conditions for average concentrations of volatile substance evolved from coating materials to reach safe concentrations in freshly coated rooms, and
3. Designs for local exhaust ventilation systems for manual coating operations (for reducing localized "high" concentrations).

The first item provides a means for applying the engineering control of substitution. Its use would not only help reduce exposures to personnel directly involved in coating operations but also to those who may be exposed to substances being evolved long after the actual coating operation has been completed. Houwink and Salomen⁽⁷⁵⁾ report that the smell of formaldehyde from urea formaldehyde adhesives is not only objectionable during the application of the glue "but may persist in the glued material ... for months or years." The papers of Riley and Boyle and Novak are both directly concerned with the rate of evolution of isocyanates from coating materials. The rate of evolution of these substances need not be appreciable for hazardous conditions to arise.

A priori estimations of the length of time necessary for average contaminant concentrations to "decay" to acceptable levels under given environmental conditions can prevent returning employees from being exposed to short-term, high concentrations. A sufficiently accurate technique would allow modification of environmental conditions as necessary to return the contaminated area to an acceptable state within the desired time interval (e.g. by increasing ventilation capacity or temperature).

Hemeon describes the application of various hood configurations for collecting and/or dispersing localized areas of high vapor concentration. The design of these devices involves the application of basic

design principles once the evaporation rate and source area are somewhat defined. Nevertheless, some of the designs illustrated are quite different from those usually found in the popular literature. There appears to be merit in the conclusion, therefore, that some further efforts directed towards developing generalized designs for the sort of operation being considered would be desirable.

Recommendations

Riley, Boyle, and Novak have laid the groundwork for the development of a test method which allows the determination of which of a number of coatings available for use is the least hazardous for workers applying it to large areas. The nature of the test procedures also allows their use to determine the "safe entry" time after the coating has been applied. It would appear to be advantageous for NIOSH to consider a program to continue efforts for refinement of such a method. Such a program would develop a testing apparatus which could be easily duplicated in a laboratory. It would then proceed to refine a calculation method for estimating necessary general ventilation rates, or conversely, for estimating the "safe entry" time for a fixed ventilation rate, and to confirm the validity of the method with actual field data. An 8 man-month effort over a time span of 6 months would most likely be adequate for such a program.

Riley reported that, at various times, the use of urethane formulations have been discontinued (in the company he works for) when it was not practical to provide adequate control. Use of the data generated by his method has, however, allowed safe resumption of the use of materials which release low concentrations of diisocyanate. Of interest is his remark that this company would not accept for use any material which generated concentrations greater than one half the current threshold limit value for any constituent.

If a method is developed which allows accurate estimation of contaminant concentrations, NIOSH may sometime in the future have the basis for the development of a regulation which limits the use of certain coating formulations in certain interior, and even exterior, applications. If there is any sort of operation for which industry is going to claim that only respirator use is feasible for control, it can be envisioned as one which involves "one-shot" applications of large amounts of surface coatings.

Whether there is any real need to develop a set of specific ventilation system design criteria for "cementing tables," wall coating operations, and the like is open to question. However, to demonstrate the feasibility of controlling such operations, notably wall and floor coating ones, by combinations of local and general exhaust ventilation, some worthwhile research efforts may be directed towards this subject area. A small effort to develop design criteria for ventilating bench surfaces, for designing canopy hoods which entrain

sufficient clean air volumes to reduce breathing zone concentrations, and for dissipating the vapors generated in wall or floor operations could also probably be accomplished with a 8 man-month effort over a time span of 6 months.

4.10 OPEN-SURFACE TANK USE

Process Description

Open-surface tanks are utilized by industry for numerous purposes. Among their applications can be included the common operations of degreasing, electroplating, metal stripping, fur and leather finishing, dyeing, and pickling

An open-surface tank operation is defined as any operation involving the immersion of materials in liquids, or in the vapors of liquids, which are contained in pots, tanks, vats, or similar containers. Excluded from consideration in this definition, however, are certain similar operations such as surface-coating operations and operations involving molten metals for which different engineering control requirements exist.

A large number of toxic substances are utilized in open-surface tank operations. Degreasing is usually done with trichloroethylene, and this solvent is the principal air contaminant in metal degreasing operations. A variety of other solvents may be employed in open surface tanks used for the cleaning and finishing of cloth and other products. The finishing of animal hides may involve open surface tanks containing depillatory agents whereas electroplating and metal pickling and stripping may involve tanks containing acids. The contaminant released from an open-surface tank may be a vapor (as is typical around degreasers) or a mist (as found around pickling tanks).

Review of Controls Employed

Ventilation is commonly employed to control emissions from open-surface tanks and a standard prescribing specific ventilatory controls can be found in 29 CFR 1910.94.⁽¹²¹⁾ A limited amount of research has been conducted to assess the adequacy of the design methods presented in the standard and to assess the effectiveness of other control measures for application to open-surface tanks.

The most recent work on engineering controls for open-surface tanks is a program conducted for NIOSH by Battelle Columbus Laboratories.⁽¹⁴⁹⁾ This program involved a series of experiments with an open-surface tank mock-up to assess the adequacy of ventilation recommendations contained in two design guides,^(11,150) to quantify contaminant generation rates, and to examine the effectiveness of floating plastic balls in reducing the need for ventilation. A number of tests were also conducted on the mock-up with a push-pull ventilation system to review design criteria for this type of system. The report for the program concludes that the use of existing design guides frequently results in the overdesign of ventilation systems and presents an alternative method of calculating

ventilation requirements. The method presented has shortcomings in that it is based on laboratory data collected with a simplified and idealized experimental mock-up and requires data on evaporation rate or gassing rate that is not currently available. Thus, Battelle's work must be considered as a limited first step toward the understanding of open-surface tank contaminant control. While a significant body of data was collected, the laboratory mock-up was limited in size and had a single contaminant in a given size room with controlled general ventilation and drafts. Furthermore, the limited resources allocated for the study limited the evaluation of mist generation phenomena.

Esman and Clearwater⁽¹⁵¹⁾ in work sponsored by the US Army have shown that the use of a cover on vapor degreasers can result in a significant reduction in solvent losses and in airborne solvent vapor concentrations, and have suggested a possible cover design. The effectiveness of a surface-active agent in reducing chromic acid mist generation from a chromium plating tank was investigated by Hama, Frederick, Millage and Brown.⁽¹⁵²⁾ Their work demonstrates that surface-active agents can reduce air contaminants caused by gassing in actual industrial settings and presents the characteristics required of a surface-active agent for use in chromium plating. There is nothing in the literature, however, suggesting a generalized procedure for selecting a surface-active agent for other open-surface tank operations.

Areas Needing Further Research

The most significant weakness of current standards and design guides on open-surface tanks is the absence of a general guideline on the evaluation of contaminant generation rates. Evaporation rates for vapors are based on work by Doolittle⁽¹⁵⁴⁾ that cannot be readily applied to substances he did not study. Gassing rates are classified as high, medium, low or nil in the current OSHA standard with no guidance provided on the definitions of these terms. It is therefore recommended that a program be undertaken to evaluate contaminant generation rates both analytically and experimentally. The objective of this program should be the development and validation of a correlation of the generation rate with properties characterizing the contaminant and the operation. The correlation developed would be confirmed through an evaluation of actual open-surface tank operations and then incorporated into design guides.

A review article by Skinner⁽¹⁵³⁾ points out that the most important source of air contaminant in many degreasing operations may be "drag-out" of solvent when the article being degreased is removed from the solvent bath. It suggests that ventilation rates determined from evaporation rate estimates may be inadequate for such operations when the effects of "drag out" are not accounted for. Battelle's work included an evaluation of the cycling of a "parts barrel" on concentrations around the open-surface tank mock-up and confirmed that the operating temperature and cycling time can significantly influence the determination of adequate ventilation rates.

It is readily conceivable that the effect of "drag out" is determined primarily by the speed with which an item is removed from a liquid bath, the projected area of the item being moved, and its wetted surface area. It is also understandable that a combination of work practice and engineering controls are required to ensure effective contaminant control. Since sufficient information does not exist to provide guidance on how controls should be instituted to ensure their effectiveness where "drag out" effects can be significant, it is recommended that a study be performed to develop appropriate guidelines. The study should review the data available in Battelle's report and any other available data on the subject, and, by evaluating typical industrial open-surface tank operations, attempt to quantify the effects of "drag out" and the controls, both work practice and engineering, necessary to overcome them.

Ancillary control techniques such as surface-active agents, floating plastic balls, and tank covers have been shown to be effective in reducing the generation of air contaminants from open-surface tanks. The extent to which these techniques can be effective, however, has never been determined in a generalized quantitative manner that would permit the reduction of ventilation requirements where ancillary controls are used. Since ancillary techniques are much less expensive and less energy intensive than ventilation, there would be advantages to the development of engineering control criteria that recognized their use. A program is therefore also recommended to identify criteria for the effective use of ancillary controls on open surface tanks. The objective of this program would be the development of guidelines for the use of tank covers, surface-active agents, and floating solids as means of reducing the generation rate of air contaminants. Specification of ventilation requirements appropriate when these controls are used would follow. The program should involve analytical prediction followed by validation on actual open-surface tank operations.

Summary of Program Recommendations

Three programs have been recommended for the development of engineering control criteria for open-surface tank operations. Suggested durations and levels of effort for these programs are listed below.

<u>Program</u>	<u>Duration</u>	<u>Effort</u>
Evaporation and Gassing rates	9 months	15-18 man-months
Drag-out	6 months	9 man-months
Ancillary Controls	9 months	1 man-year

4.11 SPRAY-FINISHING OPERATIONS

Introduction

Spray-finishing operations involve methods by which organic or inorganic materials in mist or droplet form are projected and thereby deposited onto surfaces to be coated, treated, or solvent cleaned. As an operation category, it is not commonly considered to include metal spraying or metallizing operations, or spray washing and degreasing as conducted in self-contained washing and degreasing machines or systems.

We will initially consider engineering control of such methods for the spray application of paints, and then, will attempt to assess the adequacy of these and similar controls for spray application of other types of substances. This is done because paint spraying operations have received considerably more attention in the literature than similar operations involving other materials.

Control Measures Used and Available

Control of paint spray operations conducted indoors is usually accomplished by the use of ventilated spray booths. The ACGIH Industrial Ventilation Manual⁽¹¹⁾ contains specific design criteria for both small and large spray booths, for large booths in which vehicles are painted, and for ventilation of spray painting operations conducted within trailer interiors. Additionally, there is an ANSI standard⁽¹⁵⁵⁾ for the design, construction, and ventilation of spray-finishing operations. Both these sources were extensively reviewed and utilized in the development of recommended ventilation guidelines for spray-finishing operations.

As best as can be determined, ventilation has not been considered to be an adequate control measure where large structures such as bridges, ships, or storage tanks are painted. For such operations, and indeed, for many "one-shot" operations in confined spaces, the operator is usually required to wear an approved respirator. Though ventilation has been provided in such situations, its purpose has been primarily to ensure that explosive concentrations of solvents do not accumulate in enclosed spaces.

Reichenbach⁽¹⁵⁶⁾ agrees in this by stating that "in general it is seldom possible to furnish sufficient ventilation to enclosed areas of ships which are being spray-painted to eliminate the health hazard from solvents and diluents." He continues that "it is possible and mandatory to ventilate at a rate which maintains the area free from explosive hazards." Hama and Bonkowski⁽¹⁵⁷⁾ also agree and report "the painting of large structural steel parts in steel plants poses a rather difficult problem in providing practical ventilation. Spray painting booths that would accommodate all the parts would often have to be of tremendous physical size, and exhaust air volumes would need

to be extremely large." They therefore note that a large part of spraying is done at night to reduce exposures to other workers and that spray paint operators are provided respirators.

The comments of the ILO⁽¹²⁾ and other sources suggest that "substitution" is occasionally used as an engineering control when the substances involved are shown to be highly toxic.

Available Ventilation System Criteria and Data

The ACGIH manual, as previously noted, gives specific design criteria for various types and sizes of spray booths. For large walk-in booths and air spray operations, it recommends an exhaust volume of 100 cfm/sq ft of booth cross section except where the booth is very large and very deep. In this latter case, it suggests a rate of 75 cfm/sq ft. In general, it states that the operator may require an approved respirator. For large booths into which the operator need not enter, an exhaust volume of 100-150 cfm/sq ft is suggested. The exhaust volume for airless spray operations in walk-in booths is given as 60 cfm/sq ft; for operator outside the booth, 60-100 cfm/sq ft.

Small spray booth exhaust system criteria are given separately for booths with a face area up to 4 sq ft and for booths with larger face areas. With air spray operations, an exhaust volume of 200 cfm/sq ft is recommended for the smaller booths, 150 cfm/sq ft for the large booths. With airless spray paint operations the volumes are respectively 125 and 100 cfm/sq ft.

Exhaust volumes of 100 and 60 cfm/sq ft of cross-section area are given for air and airless spray operations respectively in auto spray paint booths, and 50 cfm/sq ft is given for large drive-through booths and trailer interiors which are being coated. For this latter operation, it is noted that the operator must wear an air-supplied respirator.

In 1962, airless spray painting was a new method. At that time Brandt⁽¹⁵⁸⁾ wrote "studies were made independently by several industrial hygiene organizations and all arrived at the same conclusion, namely, that the atmospheric lead concentration in the vicinity of a painting operation with a lead-containing paint, when the pressure and the heat-with-pressure techniques were used, was not sufficiently different from the lead concentration when conventional spray painting was done to justify any change in the control measures. This was quite a blow to all concerned because the visual impression when observing the two types of spray painting was that much less mist was present when the new application techniques were used. This merely proves what all industrial health engineers know only too well, that is, conditions are not always what they appear to be."

Hama and Bonkowski investigated ventilation requirements for airless spray painting and presented their findings in a paper which is the source of recommendations in the ACGIH Industrial Ventilation Manual. Their conclusion, based upon comparative test data was "that contamination of air in a worker's breathing zone by paint mist and vapor appears considerably less with airless spray painting than with conventional compressed air spray painting." Consequently, they recommended air flow rates, for both general and local ventilation, of approximately 60 percent of conventional rates, and made the comment that "they (the rates) include some safety factor, and it is possible that they may safely be reduced further when more test data become available."

Though the aforementioned paper was primarily written with the purpose of demonstrating that airless spray operations require lower air flow rates for effective control than air spray operations, it contains data for the latter sort of operation which are of interest. For example, in a spray booth with a face velocity of 115 fpm, it is shown that the solvent vapor concentration ranged from 220 to 400 ppm. In a booth with a face velocity less than 75 fpm, the solvent vapor concentration ranged from 290-850 ppm. To be noted is that the table of recommended ventilation rates given clearly points out that "highly toxic materials such as high lead paints will require larger air volumes."

"Although comparisons are not completely valid," the authors report that, "where types of solvent were similar," airless spraying in a booth with a 120 fpm face velocity resulted in solvent vapor concentrations of 25-50 ppm. With the ventilation turned off, the concentrations were 25-230 ppm. Where such operations were conducted in an indoor area with only general ventilation, concentrations of 30 to 80 ppm were measured.

Also of interest in this paper is a table which gives the "minimum spray booth inflow air velocity to offset bounce-back" of spray from an object being coated by air paint spraying. The table, based upon a German study, lists an air velocity of 69 fpm for a distance between the spray gun and object of 59 inches, 98 fpm for 39 inches, 158 fpm for 32 inches, 296 fpm for 24 inches, and 640 fpm for 20 inches. These data clearly demonstrate the necessity for the spray gun operator to maintain the proper distance from the object being sprayed.

Describing the phenomena of "bounce-back," the authors note that "the paint particles of greater mass have sufficient kinetic energy to overcome air resistance and move toward and finally contact the object while smaller particles remain airborne and are deflected with the 'bounce-back' air stream. This results in paint fog of finely divided particles, to which the worker is exposed. Atomized droplets smaller than approximately 12 microns are generally considered of insufficient mass and momentum to overcome the drag forces of the

air..." They attribute the reduced exposures from airless operations to the fact that "approximately 2 percent of the droplets in airless spray painting are smaller than 12 microns while approximately 20 percent of the droplets in conventional paint spraying are smaller..."

The current ventilation standard in 29 CFR 1910.94⁽¹²¹⁾ is derived almost exclusively from the ANSI standard. For electrostatic and airless operations with a negligible crossdraft velocity, it gives design airflow velocities of 50 and 100 fpm for large and small booths respectively. With crossdrafts up to 50 fpm and air-operated guns, design velocities of 100 and 150 fpm are listed for large and small booths respectively. Crossdraft velocities up to 100 fpm where air-operated guns are used are noted as requiring design velocities of 150 fpm for large booths and 200 fpm for small booths for effective control.

The Michigan Department of Health⁽¹⁵⁹⁾ recommends booth face velocities of no significant difference from those suggested by the ACGIH and ANSI for air spray operations. For electrostatic paint coating, it states "there have been indications that the electrostatic process is so effective that there is little paint loss or overspray and no need for ventilation control. The latter supposition is decidedly incorrect. Despite the effectiveness of the process, there are still overspray and solvent vapors to be captured and experience has indicated that a minimum control velocity of 100 feet per minute is not only necessary but will have no adverse effects on the operation."

Hemeon⁽¹¹³⁾ recommends higher face velocities for spray painting booths than for other sources, for some applications. Specifically, he recommends a face velocity of 125 fpm for booths with a face area greater than 50 square feet when the spray gun air pressure is less than 65 psi and one of 150 fpm when the pressure is 70 to 95 psi. With smaller booth face areas, he lists even higher velocities until at an area of 4 to 6 square feet he gives 200 - 225 fpm for spray guns with the lower air pressure and 275 - 300 fpm for the higher pressure guns. He notes that the values "are subject to considerable uncertainty where the objects being sprayed are of such a shape as to result in violent, direct rebound of the over-spray" and states that under certain circumstances "a spray gun with an extension arm which positions the worker backward . . . should be given consideration".

The Massachusetts Department of Labor and Industries⁽¹⁶⁰⁾ gives specific minimum velocity requirements for air spray operations as a function of the booth face area and the spray gun pressure. These performance criteria are almost exactly those recommended by Hemeon.

Baturin⁽¹⁰³⁾ reports that "the results of all investigations which have been carried out on the paint-spraying of small and medium objects in ventilated booths indicated that, provided the correct methods of working are observed and the extraction outlet is in the rear wall of the chamber, an air speed of 0.75 m/sec (147.65 fpm) in the working opening of the chamber is sufficient to protect the painter from harm due to the inhalation of paint or solvent vapours". He adds that "the same data show also that when spraying enamel primers and paints containing lead compounds, the cited rate is insufficient. The minimum suction rate for these cases should be taken as 1.1- 1.3 m/sec (216.6 - 255.9 fpm)."

Discussion for Painting Operations

Air Spray-Painting Operations

The ACGIH manual and the ANSI standard are essentially similar in regard to suggested air velocities for air spray operations in which crossdrafts are not a significant factor. Where they can be significant, the ANSI standard suggests that the air velocity be increased by 50 fpm. From this we can conclude that ANSI recognizes the effect of crossdraft velocities in the selection of a design airflow as important whereas the ACGIH reasons that minimization of crossdrafts by baffling and other measures is a more logical approach than increasing ventilation system capacity.

A significant observation of Hemeon's recommendations is that he feels the spray gun air pressure is a significant factor. The air velocities he recommends for guns with 65 psi pressure are 20 - 40% lower than those for guns with 70 to 95 psi.

Of significance in Baturin's comments are the statements that 150 fpm is an adequate spray booth face velocity for most paint ingredients, but that 200 - 250 fpm is necessary for "enamel primers and paints containing lead compounds".

In summary, the above data allow us to make the following observations concerning air spray operations:

1. There is some difference in opinion in the literature as to the manner in which crossdraft effects can be negated. ANSI sees fit to provide users with design velocities which can overcome such effects. The ACGIH considers the elimination of such effects as being better practice.
2. There is some indication that the spray gun air pressure is a significant variable to be given consideration.
3. There are clear indications that the design criteria given in ANSI and the ACGIH manual for spray booths are inadequate for high toxicity substances.

4. It is evident that the distance of the spray gun from the object being treated is a critical factor to be given consideration.
5. The particle size distribution from the spray nozzle would appear to be a significant factor in determining the amount of paint which "bounces-back".
6. Ventilation is not considered solely adequate in many situations to maintain contaminant concentrations to levels at or below exposure limits.
7. The use of extension arms on spray guns may constitute an effective measure to move the operator backward from breathing zones of high contaminant concentration.

Airless Spray-Painting Operations

Recommendations and comments in the literature demonstrate that use of this method instead of air spray-finishing methods can in itself greatly reduce exposures for most substances. Brandt's comments, taken at face value, suggest that the benefits may not be so great where high toxicity substances are sprayed. Certain other advantages and disadvantages of the method are also worthy of mention.

Hama and Bonkowski state that since "the fluid delivery rate is higher than with conventional spraying, . . . airless spray is excellent for large areas and fast application". As a further advantage they report "because of the small rebound characteristic of airless spray painting, paint may be sprayed effectively into cavities and corners that cannot be painted with conventional spraying".* Other advantages discussed include less dependence on the operator's skill and more uniform finishes. The only disadvantage discussed concerns the fact that not all materials can be conveyed by this method since "heavily pigmented, fiber filled, abrasive, or cohesive materials" may plug the spray gun's fine tip.

* Some disagreement with this statement has been expressed by a member of the ADL staff. In a situation where he recommended the use of airless guns to reduce exposures, it was found that the method was not practical precisely for the reason that cavities were not coated properly.

Spray-Finishing with Other Materials

Perry and Chilton⁽⁸⁾ report that "flat, curved, and irregular surfaces such as tanks, vessels, boilers, and breechings are . . . insulated with . . . sprayed asbestos and/or mineral fiber-inorganic binder insulations". Benning⁽¹⁶¹⁾ states that "the spray-in-place technique makes it possible to apply urethane foam in many types of commercial applications such as exterior tanks, ducts, roofs, and pipes of simple or complex design", and notes that epoxy, silicone, and pyranyl foams can also be sprayed-in-place. Sheinbaum⁽¹⁶²⁾ reports that "the plastering industry has developed and introduced on an increasing scale a pneumatic method of applying plasters. This method consists of pumping either plaster slurries or fluffs to the point of application and spraying them on the receiving surface". Thus, it is evident that a wide variety of substances other than paints can be sprayed and possibly released into the breathing zones of spray gun operators and other workers in their vicinity.

In 1963, the Michigan Department of Health⁽¹⁶³⁾ reported that asbestos is commonly applied to interior surfaces by pneumatic means and stated that "the principal hazard in spraying asbestos is excessive contamination of the air with asbestos dust particles". Tests conducted at sampling locations from 15 to 30 feet from the spraying operation revealed dust concentrations from 14 to 59 million particles per cubic foot, considerably above the maximum allowable concentration level of 5 million particles per cubic foot in effect at that time. Another study is described where similar high concentrations were found indoors.

By 1971, the hazards of asbestos were becoming highly appreciated, and in July of that year, the Philadelphia Board of Health prohibited the use of asbestos spraying in building construction. This was the first regulation of its kind in the USA. Gorson and Lieberman⁽¹⁶⁴⁾ give the account of a two-year investigation which led to this regulation. However, the current Federal regulation, 29 CFR 1910.93a, does not specifically prohibit the use of asbestos in this manner but requires the use of engineering controls where they are feasible and respiratory protective equipment where they are not.

Benning⁽¹⁶¹⁾ discussed the various aspects of the formulation and spray-application of foams. Pertinent comments he makes for polyurethane are that "it is not practical for a man to spray at a rate of more than 5 - 6 lb/min unless he has a large open area and the appearance requirement is not critical . . . , urethane foam should be spray applied within an ambient temperature range of 65 - 100°F (since) loss of volatile components increases at higher temperatures, (and) . . . under high wind conditions care must be taken to prevent overspray and fumes from contaminating adjacent work areas". One of the common ingredients of urethane formulations is noted as being toluene diisocyanate (TDI).

The work of Peterson, Copeland, and Hoyle⁽¹⁶⁵⁾ is cited in Reference 163. These researchers indicated that hazardous concentrations of TDI can develop at varying distances downwind of the spray area depending upon "distance from the gun, spray gun elevation, formulation used, temperature and humidity of the air, air pressure of the spray gun, rate of adduct (reaction product of an excess of TDI with a polyol) used, configuration and size of the object being sprayed, wind velocity, and the use of tarpaulins to reduce air turbulence". From a review of their data, the Michigan Department of Health concluded "there is no question but that the immediate spray crew at the spray point is in a vulnerable position because of the presence of excessive concentrations of TDI . . ." They add that "the evolution of TDI vapor from the foam surface, once applied, was an insignificant problem".

Among the other ingredients used to generate polyurethane foam, Benning includes water-soluble organosilicone surfactants, small amounts of catalysts such as 2,2,2-diazabicyclooctane and/or dilaurate or diacetate di-n-butyltin, and the prepolymer formed from reaction of an isocyanate and a polyol (resin). For low-density epoxy resin systems which can be sprayed in place, he includes a class of bisphenol A-epichlorohydrin polymers which forms the basis for a series of proprietary resins. Pyranyl foams, which may or may not still be marketed because of their expense, are noted as being generated from acrolein and methacrolein tetramers, strong Lewis acids, a surfactant mixture, and possibly other substances. Silicone foams are reported to be "essentially silicon-oxygen compounds which have the nature of organic polymers in which the silicone atoms are substituted for carbon atoms".

Benning indicates that epoxy and pyranyl foams can both be applied with modified urethane spray equipment. In discussing such equipment, he describes three types of spray guns. In the first, two reactant streams are pumped through the gun under pressure and ejected in separate streams. Mixing and atomization by air are accomplished simultaneously just exterior to the spray nozzle. The reactant streams are blended internally by an air-driven agitator in the second type of gun. The components are then pumped through the gun under pressure and are atomized as a single stream by air. The third type of gun uses airless atomization. Here, the reactant streams are internally mixed by passing them together through a labyrinth under high pressure, and atomization is accomplished on discharge by the pressure drop across the spray nozzle.

Sheinbaum notes that "epoxy resins may be used in paints". In this case, he reports "the hazards involved are due principally to the solvents and may be controlled in a manner identical to that used in spray painting with other materials". He makes this conclusion because of the large proportion of the paint which is made up of solvents. Where epoxy resins alone are used, he says "during polymerization various amines are given off which may cause severe dermatosis on contact with the skin or lung irritation if inhaled".

Spray-application of gypsum plaster coats are reported by Sheinbaum to utilize a "mixture of about 20% gypsum plaster, 65% sand, and 15% water with trace amount of additives". He adds that compressed air between 16 and 22 pounds pressure is used to force the slurry out of the nozzle and that "the distance between the spray gun and the surface being sprayed may vary from a minimum of six inches to a maximum of four feet". The operation is considered to be "extremely dirty because of the considerable quantities of underspray, rebound, and drippings. Air movement within the area affects the operation and steps must be taken to close all exterior openings prior to spraying." Studies conducted by Sheinbaum to determine breathing zone dust counts in such operations revealed dust counts of 26 - 75 mppcf with a free silica concentration of 61%. Mean particle size in the dry state was 1.5 microns; 6.4 microns in the wet state.

Overall Discussion and Conclusions

For spraying of paints containing low or moderate toxicity ingredients, it is concluded that sufficient information exists for someone to design a spray booth or room which maintains exposures at or below permissible limits. Though the air velocities recommended in the literature are not universally consistent, the experience from which they are derived indicates that the most appropriate rate for any particular operation can be found in overall ranges proposed. Additionally, the use of airless spray methods instead of those using air atomization, where practical, appears to in itself be a useful engineering control. These conclusions do not in themselves, however, indicate that further research in this area is not worthwhile.

For spraying of paints with high toxicity ingredients, there does not appear to be any consensus of opinion regarding proper design velocities for spray booths. Indeed, the subject is hardly even mentioned, and thus, leads to the suspicion that an inexperienced person, using the most common recommended practices, may find results to be disappointing.

Airless spray techniques for paints, coupled with general ventilation, appear to be highly suitable for use with all types of paints for indoor applications which cannot practically be conducted in booths. Though specific data cannot be cited to prove the point, air spray techniques under similar circumstances must be considered inadequately controlled.

Virtually no information could be found which specifically demonstrates the availability or adequacy of engineering controls for spray-finishing operations utilizing substances other than paint. Though it can be assumed that indoor operations which are repeatedly performed in one location may be controlled with booths similar to those used for

paint, it cannot be assumed that the same airflows recommended are appropriate. As for paint, where "one-shot" indoor and outdoor operations are conducted, only general mechanical or natural ventilation appears to be available or used. Engineering control design criteria for such operations must, therefore, be considered only partially available and/or adequate.

Recommendations

Based upon the information presented above, and our own familiarity with spray-finishing operations, the following recommendations are made for research activities.

Spray Booth Design Improvements

All exhaust ventilated spray booths require make-up air for proper operation. In some booths the air is simply drawn through the booth face, while in others, it is introduced at some intermediate point. With the assumption made that make-up air available is free of contaminants, there is cause to consider that the precise location in the booth at which air is introduced can have a significant effect upon breathing zone concentrations. It is therefore considered desirable to investigate the potential beneficence of various booth modifications involving the entrance location of make-up air and to provide "baseline" data for spray-finishing operations in general.

The "bounce-back" of coatings being sprayed from an object being treated is a significant cause of excessive exposures. There are clear indications that spray guns using airless atomization result in considerably less "bounce-back" than guns using air atomization techniques when substances of low or moderate toxicity are sprayed. For high toxicity substances, there appears to be a lack of data as to the air flow rates necessary to achieve adequate control with either type of gun. It is therefore additionally desirable to confirm and/or determine the relative advantages and disadvantages of the two techniques and to determine appropriate minimum air velocities for effective control of highly toxic substances.

"Extended arms" for spray guns have been suggested as being useful to force the operator out of breathing zones of excessively contaminated air. It is desirable to investigate the benefits of such devices.

Specifically, it is recommended that a study be performed in which researchers perform the following tasks:

- a. Provide two spray booths; one typical of those in which the operator works inside, and one of smaller dimensions which do not allow entrance. These booths shall be designed in accordance with the NIOSH recommended ventilation guidelines for spray-finishing operations.
- b. Provide the booths with an exhaust system capable of maintaining exhaust volumes of 0 - 200 cfm/sq ft of booth cross-section for the larger booth and of 0 - 300 cfm/sq ft for the smaller booth.
- c. Provide examples of typically used air spray and airless spray gun systems for paints, examples of the various types of spray guns used for urethane and other foam applications, and examples of other such units which may be used in industry for manual spray-finishing operations.
- d. Prepare a "paint" formulation consisting of a limited number of ingredients. The ingredients selected shall be typical of those used in "paints" and shall be of widely differing and known volatility.
- e. Conduct, under controlled conditions of temperature, discharge time and rate, etc., a sufficient number of experiments to develop curves of breathing zone concentrations vs. exhaust volume for each of the spray guns. The special paint formulation shall be used for the paint spray guns; typical foam or other formulations for the others as appropriate.
- f. Conduct experiments to determine the effects of providing make-up air in various positions and in manners which can be expected to reduce breathing zone contaminant concentrations.
- g. Investigate the feasibility and benefit of using "extension arms" on spray guns. Of possible usefulness might be the utilization of make-up air to form an air curtain in front of the operator while he uses a spray gun with an extended arm which penetrates the curtain.
- h. Utilize the data obtained to develop specific ventilation system design criteria for coatings of varying physical, chemical, and toxicological characteristics.

A level of effort of about two man-years over a time span of 12 months is estimated as sufficient for such a program if the special "paint" formulation consists of ingredients whose concentration in air can simply be determined.

Engineering Controls for Exterior and "One-Shot" Interior Operations

It is difficult to conceive of engineering controls, other than those of substitution or use of airless spray guns, which can practically prevent operator exposures to excessive contaminant concentrations during exterior and "one-shot" interior operations. Research into substitution for the types of substances being considered must be considered not to be a feasible activity for NIOSH, and the use of airless spray techniques does not truly require further research if the first recommendation above is accepted. Personal protective and administrative controls must therefore continue to be relied upon.

Consolidation and Dissemination of Information

This evaluation of spray-finishing operation control technology has enumerated the various factors influencing worker exposures. Additionally, it has recommended research which may lead to a firm and accurate data base from which ventilation system performance criteria can be generated which is known to be applicable and adequate for a diverse set of circumstances. If the recommendation above is accepted, and there is confidence that the data generated is useful, it might then be considered advisable for NIOSH to produce a manual which reviews the hazards associated with these operations, the experience noted in the literature, the results of its own test program, and those "good practices" which can reduce worker health problems. Since no new data would need be generated, a time span of six months and a level of effort of six man-months would be expected to be adequate for this endeavor.

4.12 TEXTILE COATING AND DYEING

Introduction

The equipment and procedures described and discussed in the following are normally considered representative of activities conducted by the textile industry. Nevertheless, many of them are also utilized for the treatment of paper, wood, plastic, and rubber products. Thus, although the following is written in the context of their use specifically in the textile industry, it is somewhat applicable to operations conducted in a number of others, particularly in regards to coating operations.

Dyeing operations are conducted to impart colors to fabrics for decorative purposes. Coatings are applied to textiles (and other flexible materials) to render them resistant against penetration by water and other liquids and solutions, to apply an adhesive of some sort before further processing, etc. Werber (166) states that "the field of chemical finishing of fabrics, in particular, has been blessed with a plethora of new chemicals, dyes, and techniques of application which have given us permanent press shirts and outerwear, washable wool, soil-repellent, water-repellent, and soil-release finishes, and a spectrum of bright colors in both men's and women's wear."

The plethora of new chemicals and dyes to which Werber refers, and the multitude of those whose use has continued from the past to the present, represent potential occupational health and industrial hygiene problems for the textile industry and others which have adopted its methods. In the following, we describe some of the basic processes, health hazards, and engineering controls associated with these operations.

Dyeing Processes (12, 31, 76, 167-170)

The classes of dyes are many. Included are "basic, or cationic (dyes); acid and premetalized; chrome and mordant; direct and developed direct; sulfur, azoic, vat, disperse, and reactive" types. (31) Each of these classes is in turn comprised of a variety of chemical substances; the purpose of all of which is to produce a particular color in the fibers of a material by chemical reaction or strong physical binding forces. To promote the dyeing process, various substances other than dyes themselves may be found in dye formulations.

Simply stated, dyeing involves the introduction of a material into a vessel containing a dye solution. This may be accomplished either in a batch or continuous mode depending upon the demand for a given product. Introduction is achieved by means of rollers, racks containing skeins, or in loose mesh bags as appropriate. Depending upon the particular process being used, the operation may be conducted at various elevated pressures and temperatures or at atmospheric pressure and more moderate temperatures. The equipment used may be open or totally enclosed.

A considerable amount of chemical pretreatment of fabrics is necessary before the actual dyeing operation can take place. Wool must be scoured with a soap and soda ash solution, bleached with hydrogen peroxide or sulfur dioxide, passed through a sodium carbonate bath, and then washed thoroughly. Cotton is first desized in a diastase solution. Depending on the process used, it may then be subjected to sodium hydroxide, sodium carbonate, turkey red oil, hypochlorite solution, sodium bisulphite solution, and dilute hydrochloric or sulfuric acid. Even a synthetic such as nylon can require scouring, some form of setting treatment and, in some cases, bleaching.

Until recently, most dyeing operations were conducted with aqueous solutions of dyes. To reduce water pollution problems, however, solvents are being used to replace water. Howrey(169) describes some of the equipment and systems available for solvent dyeing, scouring, and finishing. Many of the units are clearly stated as being totally enclosed and capable of solvent recovery.

A recent development in the dyeing of synthetic carpet yarns is the non-aqueous process of dyeing with ammonia invented by Arthur D. Little, Inc. (170) The only ingredients necessary for this process are the dye stuff and liquid ammonia. Available equipment can easily be converted to this system, and the process is inexpensive. Another benefit of the system is that the exhaust hoods which are vital to the system

serve the dual purpose of protecting workers' health and recovering ammonia.

Coating Operations

The materials used to coat fabrics include cellulose nitrate, cellulose acetate, natural rubber, synthetic rubbers, polyvinyl chloride, polyvinyl chloride-acetate copolymers, polyvinyl chloride-vinylidene chloride copolymers, polyvinyl butyrol, drying oils, various varnishes, polyester resins, silicon resins, and numerous other substances. These may or may not be dissolved in organic solvents for ease of application.

For the purposes of this report, we shall discuss the two basic coating methods and the equipment involved in each. The first general method is "spread coating" and the second is "roll coating." (1)

Spread Coating (1)

Floating Knife Coaters

Viscous solutions with a high content of solids (i.e. cellulose nitrate and vinyl solutions) are applied to fabrics with floating knife coaters, as are other solutions such as organosols and plastisols. From a take-off roll, the fabric is fed over two support rolls between which a spreader knife is mounted. The coating material is applied in front of the knife and smoothly coats the fabric passing underneath the knife. The specific thickness of the coating depends upon the type of knife used, the angle at which it is set, and the tension on the fabric.

Rubber Spreaders

The rubber spreader is used to coat fabric with viscous rubber solutions as well as vinyl and other viscous solutions. Its mechanical configuration is generally similar to that of a floating knife coater with the exception that the knife is mounted directly above a roll made of rubber.

Blanket Coaters

Low-strength materials may be coated with shellac, vinyl, rubber, lacquer, or varnish on a blanket coater. The configuration of this coater is also similar to that of a floating knife coater with the exception that the two support rolls over which the fabric passes have a rubber sheet over them in an endless loop configuration. This sheet forms the "blanket" and supports the fabric passing underneath the knife.

Roll Coating (1)

Roll coaters are more efficient than spread coaters and are thus better suited to rapid, quantity production. Their output is limited only by the capacity of the dryer and the speed of coating solution feed. Generally speaking, all of these operate by the transfer of coating material to a roller, and then from a roller to the fabric.

Calenders are used to apply vinyl compounds, synthetic rubbers, and natural rubber. Reverse roll coaters coat varnishes, organosols, and lacquers. Roll kiss coaters are suitable for applying "hot-melt coatings," and air knife coaters are advantageous for coating vinyl and rubber latexes. Solvent solutions are not applied with air knife coaters since explosive solvent-air mixtures can easily be formed. Finally, dip coaters are particularly well suited to the application of oleoresinous varnishes. These coaters function by causing the fabric to actually "dip" into a bath of coating material.

Health Hazards Associated with Textile Dyeing and Coating

Dyeing

According to the ILO, (12) dyes do not pose a serious health hazard to workers under conditions of ordinary use in industry. Apparently the main risk is from the primary and intermediate materials, reagents, and solvents. Certain dyes are known to cause bladder cancer in humans, however, and other dyes are known to cause cancer in experimental animals (i.e. rhodamine B, magenta, 2-naphthylamine, and dianisidine).

The "fast salts," azoic dyestuffs, present special health problems because they can cause respiratory sensitization and asthma. These highly reactive compounds are not actually dyes themselves, but they react with chemicals in the fiber to form a dye on the fiber.

Many chemicals used in dyeing can cause skin irritation and dermatitis. Organic solvents and corrosive acids and alkalies are also capable of such effects. (171)

There is a potential for exposure to chlorine in many factories which use gaseous chlorine, bleaching powder, or hypochlorite solutions for bleaching. Chlorine, a powerful irritant, can cause skin irritation, eye irritation, and delayed pulmonary edema.

There are numerous chemicals used in the application of dyes, and depending upon the particular conditions (i.e. open systems vs. closed systems, spray applications vs. dipping operations, etc.), there are varying degrees of potential for worker exposure.

That open dye vats may be a source of airborne contaminants is evidenced by statements of Stevens. (172) He states that "odorous emissions from open dye vats can . . . create air pollution which can be difficult and expensive to control." Of interest is his remark that the variety of chemicals used in complex dyeing processes "makes evaluation of stack emissions difficult and air pollution control equipment not easy to select."

Coating

The tremendous diversity of chemicals, equipment, and processes for textile coating operations demonstrates that there is also considerable potential for these to present health hazards. Recently, a

coated fabric plant had to cease the use of methyl butyl ketone when several employees displayed nerve illnesses believed to be caused by this compound. (173,174)

Many rubberized fabrics are made using the compound resorcinol formaldehyde. This chemical is put on by a weaver in a water system. Industrial weavers, however, have misgivings about the use of this chemical solvent because of explosion and fire hazards, toxic fume exhaust problems and other reasons. (171)

Controls

Concerning worker exposure to chlorine during bleaching operations, the ILO recommends that bleaching vats be constructed as closed vessels, "with vents that allow a minimum escape of chlorine . . . The valves and other controls of the tank in which the liquid chlorine is supplied to the dyeworks should be controlled by a competent operator since the possibilities of an uncontrolled leak could well be disastrous." (12)

Textile Technology, Inc., has developed solvent processing systems which use perchloroethylene and "are claimed to dye polyester and all other common fibers, as well as scour, bleach and finish on converted conventional equipment." In beam-and-package dyeing operations superheated steam is used to vaporize the perchloroethylene from the dyed fabrics. Pariser points out that "conversion of equipment for solvent systems does not eliminate its use for aqueous processing . . . Enclosure to contain fumes, mounting of a condenser and in-and-out piping for the perchloroethylene to and from the still is all that is involved." (176)

In the ammonia dyeing system discussed previously, canopy hoods, mounted over converted space dyeing equipment, serve the dual purpose of protecting the worker and recovering ammonia.

Discussion and Conclusions

This brief study of coating and dyeing operations provides an overview of an industry which utilizes a multitude of chemicals, equipment types, operating procedures and processes. It provides us with sufficient information to develop the following observations.

The first is that very little published information exists describing the specific exposures which may occur, certainly not enough to allow determination of all the individual processes which may require controls. Thus, it is impossible to determine whether controls are available and adequate for all. That they are available and used for some is, however, evident.

Another observation is that many of those operations conducted in the open involve the use of toxic substances at elevated temperatures or the use of volatile solvents. Stevens suggests that dye vats may pose a problem. That evaporated solvents from various coating apparatus might cause a health hazard can be safely assumed.

These observations alone are sufficient to lead to the conclusion that further study of these operations is warranted to more fully describe them, the substances used, the contaminants which might be evolved, and the controls, if any, which appear necessary.

Recommendation

It is recommended that NIOSH consider a survey of selected plants conducting dyeing and/or coating operations with the purpose of determining the need for, availability, and adequacy of engineering controls. The program should have three objectives; the classification of the various individual operations conducted; the characterization of harmful exposures; and the development of any needed engineering control design criteria. An effort of 18 man-months over a time span of 9 months is estimated as adequate for such a program.

4.13 WELDING OPERATIONS

Introduction

The term "welding," as used by the American Welding Society, (177) includes a large number of operations by which materials - usually metals - are joined, cut, or surfaced. From the standpoint of ventilation requirements, the following specific operations are of concern:

Gas welding	Gas shielded-arc welding
Oxygen cutting and gouging	Plasma arc welding
Torch brazing and soldering	Submerged arc welding
Shielded metal-arc welding	Flux cored arc welding
Arc cutting and gouging	Thermal spraying

These operations are of concern because the potential exists with each for the generation of air contaminant concentrations in excess of the exposure limits. However, excessive air contaminant concentrations have not actually been demonstrated or reported with all of these operations.

Each of the above welding operations generally involves melting of a metal in the presence of a flux or a shielding gas by means of a flame or an electric arc. The operation may produce gases or fumes from the metal, the flux, metal surface coatings, or surface contaminants. Certain toxic gases such as ozone or nitrogen dioxide may also be formed by the flame or arc. In addition, certain of these operations - such as cutting, gouging, and spraying - release air contaminants in high velocity streams. As a result of these factors, a welder may be exposed to a wide variety of air contaminants. Many studies have been performed of the welder's environment, and a review of existing data on this subject is presented in Reference 178.

Ventilation is the principal method employed to control exposures of welders to air contaminants. Ventilation methods used include three conventional methods: general mechanical ventilation, free-standing, open exhaust hoods, and ventilated enclosures, as well as three methods developed primarily for welding operations: crossdraft tables, downdraft tables, and gun-mounted open hoods.

Existing Ventilation Criteria

The most comprehensive set of guidelines for ventilation of welding operations is found in Reference 179 and has been incorporated without substantial changes into the General Industry Safety and Health Regulations. (180) These guidelines, which are formulated by the ANSI Standards Committee Z49, specify minimum ventilation requirements for general mechanical ventilation, free-standing open hoods, enclosures, and downdraft tables. Guidelines also are included for the control of certain toxic materials encountered in welding operations.

Another set of guidelines for ventilating welding operations is contained in the Industrial Ventilation Manual. (11) These guidelines cover the use of free-standing open hoods, crossdraft tables, and enclosures with certain welding operations.

A third set of guidelines is contained in a report of a NIOSH-sponsored research program on the control of welding fumes. (181) This report contains detailed performance data for a free-standing open hood and a crossdraft table used with arc welding operations.

These are the only publications found in this program which provide quantitative guidelines to ventilating welding operations. Of these three publications, only the third contains ventilation system performance data. The first two publications offer no supporting data for the ventilation guidelines presented.

Identification of Problem Areas

Problem areas in the ventilation of welding operations can be identified by a table defining combinations of specific welding operations and ventilation methods, as shown in Table 7. Entries are contained in the table where guidelines exist for specific operation-method combinations. The spaces in the table without entries represent problem areas for which ventilation method performance data and ventilation guidelines are not available or do not exist. However, not all of the open spaces in the table are of equal significance. For example, the use of enclosures is not common with welding operations except for thermal spraying which presents a unique problem in contaminant control.

TABLE 7

PROBLEM AREAS IN VENTILATION OF WELDING OPERATIONS

Operation	Gen. Mech. Ventilation	Open Hood	Ventilation Methods			Enclosure
			Crossdraft Table	Downdraft Table	Gun-Mounted Hood	
Gas Welding	G(180)	G(180)		G(180)	NA	
Torch Brazing and Soldering	G(180)	G(11, 180)		G(180)	NA	
Shielded Metal Arc Welding	G(180)	GD(181)	G(11)	G(180)	NA	
Plasma Arc Welding	G(180)	G(180)		G(180)	NA	
Submerged Arc Welding	G(180)	G(180)		G(180)	NA	
Gas-Shielded Arc Welding	G(180)	G(180)	GD(181)	G(180)		
Flux Cored Arc Welding	G(180)	G(180)		G(180)		
Oxygen Cutting and Gouging	G(180)	NA	NA	G(180)	NA	
Thermal Spraying	NA	G(11)	NA	NA	NA	G(11)

Symbols: G = Guidelines only

NA = Not applicable

GD = Guidelines and supporting data

Numbers in parentheses indicate references.

The most obvious problem areas revealed by Table 7 are with the use of crossdraft tables and gun-mounted open hoods. Another problem area, which is less obvious, is the need to verify the ventilation guidelines for which no supporting data are available. These problem areas are discussed in the following section.

Discussion of Problem Areas

Performance of Crossdraft Tables

A crossdraft table is a horizontal work surface with a slot exhaust hood mounted on the edge opposite the worker's position. Varying degrees of shielding or flanging are used with the hood and table to increase the effectiveness of the hood in controlling contaminants generated by the operation performed on the table.

A detailed study of crossdraft table performance with gas shielded-arc welding is described in Reference 181. This particular welding operation was selected for the study because baseline tests of several different operations indicated that gas shielded-arc welding has a high potential for causing excessive exposures to welding fumes.

In the absence of experimental data on the performance of crossdraft tables with other welding operations, it is reasonable to use the guidelines developed for controlling fumes from gas shielded-arc welding. However, it is likely that these guidelines will require ventilation rates which are either too high or too low for other operations. Consequently, it is recommended that a research program be undertaken to evaluate the performance of crossdraft tables with welding operations other than gas shielded-arc welding. This program could be completed most economically by considering it as an extension of the investigation described in Reference 6. Using the same experimental procedures, other welding operations could be investigated and ventilation guidelines developed analogous to those developed for gas shielded-arc welding.

Performance of Gun-Mounted Exhaust Hoods

Gun-mounted exhaust hoods are small hoods attached directly to the welding guns used in gas shielded-arc welding and flux cored arc welding. The advantages of gun-mounted hoods are that they require relatively low ventilation rates since they are located close to the contaminant sources, and they interfere minimally with the welding process because of their small sizes. Disadvantages of gun-mounted hoods are that they tend to disrupt the performance of the shield gas, thereby requiring higher shield gas flows, and they add complexity and weight to the welding gun.

Data on the performance of gun-mounted hoods are limited in availability and consist essentially of manufacturer's promotional literature and the results of a single test series in Reference 181. An investigation of gun-mounted hood performance is necessary to determine whether the approach actually is effective in contaminant control and to determine design and operational guidelines for the use of the hoods. It is recommended that an investigation be initiated to accomplish these two purposes.

To examine the contaminant control effectiveness of gun-mounted hoods, it is suggested that an experimental investigation be conducted similar to that described in Reference 181 but broader in scope. Commercially available gun-hood combinations should be tested with a variety of work materials. Quality of weld and effectiveness of contaminant control should be measured as functions of shield gas and exhaust flow rates. The tests should include actual industrial production operations so that the influence of the welder's procedures can be observed.

The data derived through the first task may be sufficient to establish design and operational guidelines for gun-mounted hoods. Otherwise, additional tests will be necessary to determine the effects of gun and hood design and operational parameters. The test results should then be transformed to a set of guidelines for the use of gun-mounted hoods.

Verification of Existing Guidelines

Most of the ventilation guidelines indicated in Table 7 are of uncertain origin and are unsupported by experimental data. Consequently, the effectiveness of these guidelines in controlling exposures to welding fumes is entirely unknown to NIOSH and OSHA. Consequently, it would be prudent for these guidelines to be verified by a program of exposure measurements under actual production welding operations.

It is recommended that a program be undertaken to evaluate the validity of existing guidelines for ventilation of welding operations. The program should consist of field measurements of welder exposures under as wide a variety of conditions of welding operations as possible. The measurement program should include careful measurements of ventilation system parameters so that the measured exposures can be correlated with both welding operation and ventilation system parameters. The results of this program can be used to modify existing ventilation criteria as necessary to validate the criteria.

Summary of Program Recommendations

Three programs have been recommended for the development or validation of ventilation criteria for welding operations. Suggested durations and levels of effort for these programs are listed below.

<u>Program</u>	<u>Duration</u>	<u>Effort</u>
Crossdraft Table Performance	1 Year	1-2 man-years
Gun-Mounted Hood Performance	1 Year	1-2 man-years
Existing Guidelines Validation	1 Year	1-2 man-years

5. SUMMARY AND PRIORITIZATION OF RESEARCH RECOMMENDATIONS

5.1 INTRODUCTION

All research recommendations developed in this report represent problem areas where further study can provide benefits to the working population, but some recommendations can be expected to be more worthy for implementation than others. Therefore, there is definite advantage to their prioritization.

5.2 APPROACH

In the conceptualization of this program, it was assumed that any methodology to rank recommendations would somehow take into account numbers of employees exposed, the severity of the effects of exposures, and the effectiveness of all control measures available for use, including those other than engineering controls. This was based on the supposition that most problem areas identified would be associated with particular industries and would involve limited numbers of identifiable toxic substances. The a priori feeling was that those operations which are common to many industries, and which therefore involve large numbers and types of toxic substances, would be generally found to be adequately controllable with current engineering control techniques.

As can be discerned from the results of this study, this was not always found to be the case. Close study of the technology upon which popular guides for engineering control design are based resulted in the identification of significant inadequacies. The available resources for investigating operations requiring engineering controls were therefore mostly expended upon these common operation categories, categories which defy characterization by parameters enumerated above. It became obvious that any prioritization methodology utilized would need to be based upon other, yet valid, considerations.

In reviewing and closely inspecting the various recommendations made, and the reasons why they were proposed, it became evident they could be characterized by six distinct classifications. Comparison of these classifications indicated that these could logically be ordered to demonstrate the relative importance of the various recommendations.

Table 8 lists these classifications in their order of importance. The highest priority classification is 1, the lowest is 6. In the following, the reasoning behind their formulation is presented and discussed.

Classification 1 represents those research recommendations which would result in control technology not presently available, but for which a definite need can be envisioned and/or justified; i.e., these controls are unavailable, but needed.

Table 8

Priority Classifications for Research Recommendations

Classification

1. Guidelines do not exist. Subject not previously given sufficient attention, but perceived to be important.
2. Guidelines have been shown to be contradictory, often capable of resulting in inadequate control, and not based upon firm scientific principles.
3. Guidelines exist but origin uncertain and adequacy in some situations unconfirmed by data in the public domain. Effective control can be assumed in most circumstances.
4. Numerous guidelines or methods of control available. Some may result in adequate control in some or all situations; some may not. Consolidation and dissemination of information appears warranted after determination and verification of adequacy of best ones.
5. Guidelines do not exist, but adequate methods of control available. Research would result in savings of materials or energy or would result in more convenient control measures.
6. Necessity of research not addressed by literature. Recommendation presented as an idea for further consideration. Findings may or may not be significant.

Classification 2 represents recommendations with the purpose of examining guidelines commonly found in the literature which are contradictory, are not based upon firm scientific principles, and/or have been reported to result in inadequate control in various applications. The guidelines referred to are those generally based upon some researcher's personal experience. They are sometimes noted as being "general averages", but more often than not, are presented without detailed qualifying remarks on their usage; i.e., these controls are available, but sometimes inadequate. In comparison to the first classification, this one must obviously be given a lower priority.

The third category pertains to very specific guidelines which exist in the literature. While they may be somewhat contradictory in some aspects for some problem areas, they are generally quite consistent in their recommendations. Typically, there are no indications that their use results in inadequate control. Their major failing is, however, that they are of uncertain origin and based on data which is unavailable in the public domain; i.e., these controls are available, can be presumed to be adequate until proven otherwise, but should be studied to ensure that they are indeed adequate. Since they are available, and since they have not been shown to often lead to inadequate control, it is evident that this Classification deserves a lower priority than those preceding it.

Classification 4 represents recommendations which suggest the consolidation and dissemination of control method guidelines to industry. These recommendations generally were derived from realizations that numerous methods of control exist for some operations, that some methods are better than others under some circumstances, and that no one source of information exists which broadly discusses the subjects of interest. Since the development of a manual or set of guidelines which satisfy the objectives of these recommendations is predicated upon the prior confirmation that control methods presented are adequate, the priority of this classification can also be considered lower than those preceding; i.e., these recommendations are for distributing information after such information is sufficiently available.

Some of the recommendations made involve the development of new methods for controlling operations which can be adequately controlled with existing technology. The desirability of such studies stems from their perceived capabilities to result in equally effective control techniques at a saving in materials utilized, energy expended, etc.; i.e., controls are generally available and adequate but "better" control measures appear to be feasible. These recommendations are thus represented by Classification 5.

The research recommendations represented by Classification 6 are felt to have considerable merit. However, since their need cannot be fully justified by comments in the literature or other data, and since they are simply presented as good ideas for further consideration, they

are assigned the lowest priority. There is no assurance that this research would provide any tangible benefits.

5.3 RESULTS

Table 9 summarizes the specific engineering control research programs recommended in this report and presents their classifications as determined from the procedure described above. Though certain other types of programs were recommended in Section 3, their significantly different nature does not allow their inclusion. Hence, their merit must be judged on an individual basis.

Classification of the 37 research recommendations by the scheme presented does not result in an ordering in which one recommendation is shown to be most important, another as second most important, etc. Indeed, 12 recommendations are assigned a classification of 1, 9 are assigned a classification of 2, and so forth. Attempts made at internally ordering these groups so that they could be ultimately assembled in an absolute order were not successful. Quantitative methods were stymied by the same lack of data which necessitated the classification procedure utilized. All qualitative methods could not be justified as being formulated on any other basis than personal opinion. Thus, it was concluded that more definitive prioritization of these recommendations requires data not available to this study.

5.4 CONCLUSIONS

It is evident that some degree of engineering judgement was required to prioritize the numerous recommendations into the groups presented. While not everyone may agree with the particular placement of any given recommendation, we are confident that they are ranked as best as can be accomplished using the information available to this study.

TABLE 9. PRIORITIZED SUMMARY OF RESEARCH RECOMMENDATIONS

Subject Area	Classification	Programs Recommended	Estimated Effort (man-months)	Estimated Time Span (months)	Comments
Abrasive Machining Operations	1	Investigate use of open and shaped hoods for abrasive machining of non-metals; develop ventilation criteria	24-36	12	Criteria available for woodworking operations, lacking for all other non-metals (i.e. plastics, ceramics asbestos products, etc.)
	5	Investigate performance characteristics of LVHV hoods; develop ventilation criteria	24-36	12	Present guides are non-specific, design and application are now trial-and-error processes
	3	Collect performance data from exhausted enclosures	12-24	9	Additional data would provide firmer base for developing ventilation guidelines
Chemical Processes	1	Review existing literature concerning types of equipment train fittings used in industry, their leak-resistance, reliability, etc. Attempt development of design guidelines for reducing exposures	24	12	Most valves, pumps, pipe joints, etc. leak to some extent, some more than others. Proper selection of fittings can significantly reduce exposures
	1	Describe cleaning methods used and define their appropriateness under various conditions	8	6	Some methods are better than others under certain circumstances; when and where they are requires definition
Cleaning and Maintenance	6	Investigate possibility that respirable toxic dust can escape filters in typical vacuum cleaners	2	2	Simply an idea; no knowledge if this is realistic problem area; might be a problem when highly toxic, fine dusts are collected

TABLE 9 (CONTINUED)

Subject Area	Classification	Programs Recommended	Estimated Effort (man-months)	Estimated Time Span (months)	Comments
Cleaning and Maintenance (Cont'd)	1	Perform user need and engineering feasibility study for a portable local exhaust system with an internal air cleaning device for vapors and fumes	12	9	Adequate engineering controls for maintenance work not available for controlling vapors and fumes released; suggested equipment may be useful for both EPA and OSHA compliance purposes, emergency leak control, etc.
Dryer and Oven Use	4	Review state of the art of oven ventilation design methods; develop ventilation guideline or manual which stresses all important factors	6	5	Many important factors do not appear to be properly stressed in literature; specific control criteria only available for continuous tunnel type dryers
Grinding, Crushing, and Screening Operations	1	Compile information on control of equipment; identify and fill data gaps; develop control guidelines	24	12	Guidelines exist only for a few types of equipment used in specific industries
Laboratory Operations	1	Evaluate state of the art of biological cabinet design; formulate design and operation guidelines	6	9	No generally accepted design or operational criteria exist presently
	3	Verify effectiveness of existing ventilation guidelines; devise performance measurement procedures; update guidelines	24-36	18	Guidelines exist but data which verifies their effectiveness are unavailable

TABLE 9 (CONTINUED)

Subject Area	Classification	Program Recommended	Estimated Effort (man-months)	Estimated Time Span (months)	Comments
Materials Handling Operations	6	<u>Belt Conveyors</u> Investigate feasibility for material test method to determine need for controls for belt conveyor transfer points, etc.	6	6	No convenient test method exists to determine if conveyed substance will present respirable dust problem during transfer operations
	1	Develop and validate test method described above if need is identified	24	12	
	2	Critically review methods to determine amount of air entrained with falling material	3	4	Various methods proposed in literature - all different
	2	Develop method for air temperature corrections necessitated by heated substances	3	4	Unconfirmed empirical methods exist; method based on rigorous analytical study or adequate experimental data base unavailable
	2	Using methods developed in above, develop comprehensive calculation procedure for belt conveyor transfer point ventilation; determine necessary control air volumes, validate method	8	6	This program incorporates data from previous programs recommended; popular guidelines for controlling this problem are too simplistic, may lead to inadequate control
	6	<u>Other Conveyor Types</u> Conduct survey to determine extent to which use of other conveyor types can result in exposures	5	8	Much attention given to belt conveyors; no indication in literature that other open types require controls

TABLE 9 (CONTINUED)

Subject Area	Classification	Program Recommended	Estimated Effort (man-months)	Estimated Time Span (months)	Comments
Materials Handling Operations (Cont'd)	1	If need exists, extrapolate belt conveyor controls to other conveyor types	1	2	
		<u>Bin Filling</u>			
	2	Apply technology developed for falling materials	2	2	Existing guidelines are too simplistic
		<u>Bucket Elevators</u>			
	2	Apply technology developed for falling materials	2	2	Existing guidelines are too simplistic
		<u>Chutes</u>			
	2	Apply technology developed for falling materials	2	2	Existing guidelines are too simplistic
		<u>Bag Filling</u>			
	2	Classify types of bags and filling machines; determine how combinations best controlled	8	6	Operation repeatedly noted as being hazardous in many industries; adequacy of controls unknown; typical guides contradictory
		<u>Drum Filling</u>			
2	Apply technology developed for falling materials	2	2	Existing guidelines are too simplistic	
3	<u>Bag Integrity</u> Review DOT container regulations as to how they affect work place exposure probability	24	12	Objectives of DOT regulations are conceivably different than those of NIOSH or OSHA	

TABLE 9 (CONTINUED)

Subject Area	Classification	Programs Recommended	Estimated Effort (man-months)	Estimated Time Span (months)	Comments
Materials Handling Operations (Cont'd)	2	<u>Bag and Drum Emptying</u> Survey handling procedures for packaged solids; develop guide for work practices and engineering controls	6	5-7	Noted as hazardous operation in many industries; adequacy of controls unknown; control guides are contradictory
	4	<u>Overall</u> Produce manual consolidating state-of-the-art technology and methods for controlling materials handling operations	24	12	Numerous control methods exist for each type of operation; no single guide to the subject exists
Non-spray application	1	Develop test method for coatings	8	6	Method would allow comparison of coating hazards, determination of "safe entry" times, and determination of ventilation criteria
	1	Develop local exhaust ventilation criteria for coating operations	8	6	Guidelines only found in Hemeon; need exists for consolidation, better definition, and validation
Open-Surface Tanks	5	Develop analytical method for determining evaporation and gassing rates; validate; incorporate into ventilation guidelines	9	6	Quantitative estimation technique is not commonly recognized; existing guidelines result in frequent overdesign of exhaust systems.

TABLE 9 (CONTINUED)

Subject Area	Classification	Programs Recommended	Estimated Effort (man-months)	Estimated Time Span (months)	Comments
Open-surface Tanks (Cont'd)	1	Investigate rate of immersion and vapor "drag-out" effects on contaminant concentrations; recommend appropriate work practices, work speeds	15-18	9	Improper practices can easily liberate vapors from control envelopes of local exhaust systems
	5	Investigate effects of ancillary control measures; develop guidelines for their use	12	9	Methods potentially very useful; proper guidelines do not exist for their use; other adequate controls exist however.
Spray-finishing Operations	3	Investigate spray booth design criteria; develop firm data base; improve existing guidelines	24	12	Present guidelines for paints not adequate for high toxicity substances; relative degree of exposures from various application techniques unknown; criteria unavailable for substances other than paint.
	4	Produce manual for engineering control of such operations	6	6	
Textile Coating and Dyeing Operations	1	Survey plants conducting these operations; determine need for, availability, and adequacy of engineering controls	18	9	Potential for exposures is considerable; virtually no engineering control criteria are available in the literature

TABLE 9 (CONTINUED)

Subject Area	Classification	Programs Recommended	Estimated Effort (man-months)	Estimated Time Span (months)	Comments
Welding Operations	5	Investigate performance characteristics of crossdraft tables	12-24	12	Criteria presently exists only for gas shielded-arc welding
	5	Investigate gun-mounted hood performance	12-24	12	Present data very limited; design and operational guidelines are incomplete
	3	Verify existing ventilation guidelines	12-24	12	Most common guidelines are of uncertain origin and are unsupported by experimental data

6. GENERAL OBSERVATIONS AND RECOMMENDATIONS

6.1 INTRODUCTION

In the performance of this study, a number of concepts, ideas, observations etc. were developed or made which were not suited for inclusion into the preceding sections of this report. In the following, the most worthwhile of these are briefly presented and discussed.

6.2 DATA COLLECTION

To satisfy the requirements of OSHA and the EPA, industry has itself conducted considerable research to develop effective control measures. Some of this work has resulted in novel techniques which have been reported upon in the general literature. Much of it, however, has simply involved the taking of air samples or other observations to define the problem, and the subsequent design of some sort of process modification or other engineering control to ameliorate it. Where this has involved only the application of basic principles, the successful control measure has not necessarily been reported upon to the industrial community. It can be perceived that this individualized approach by industry in developing effective control measures can lead to duplication of effort and unnecessary expenditures of resources on the part of companies or individuals addressing a problem already solved elsewhere.

NIOSH is in an ideal position to act as the focal point of government, labor and industry for promoting the transfer of technology between individual companies or industries. It is therefore suggested that NIOSH more fully develop the necessary procedures and mechanisms to facilitate such technology transfer and to encourage its occurrence.

The means by which NIOSH may act are many and commonly utilized by other agencies involved in research and development activities. They include (1) periodic sponsorship of conferences or seminars involving parties interested in a particular subject area, (2) complete publication of conference proceedings, (3) development and maintenance of a data base which can be accessed freely, and (4) the performance of industry-wide surveys to ascertain the state-of-the-art of engineering control utilization.

6.3 EXPERIMENTATION TECHNIQUES

Popular sources of ventilation system design criteria usually present a particular hood design and a particular suggested exhaust volume, hood face velocity, or capture velocity for each type of operation treated. The air velocities or volumes are usually either a single value or a range of values. Rarely, separate values or ranges may be given for use depending on whether a substance is simply a nuisance material or is toxic.

It is commonly understood by personnel trained or otherwise experienced in the field of industrial hygiene engineering that these guidelines are not universally capable of resulting in effective control of contaminants under all circumstances. Indeed, it is realized that the given criteria are presented as "averages" which have through long-term experience been found to be generally applicable to many specific operations and which probably are not completely adequate where substances of high toxicity are handled.

While there is great benefit to be found in the use of these guidelines, there is, however, cause to consider that they are lacking in many respects. Specifically, the point can be made that they can be faulted for not defining the specific circumstances under which they are applicable and the specific degree of control which they can be expected to provide. Without such data, there would appear to be a considerable potential for criteria to be applied to situations for which they are not appropriate, thereby resulting in ineffective control. It is our feeling, therefore, that NIOSH, in all of its research work, should ensure that the circumstances for which a particular control has been developed be completely defined and included as a part of any engineering control design criteria presented to industry.

Carrying this concept a step further, one can also see cause for recommending that research not be conducted solely to determine what hood dimensions, capture velocities, etc. are necessary to achieve a specific and desired degree of control. Rather, it should be conducted to define the degree of control which can be achieved by varying control parameters through practical ranges. This would result in design criteria which are not presented as a single hood design with a single associated air velocity or volume, but which allow selection of a design which more precisely provides the degree of control desired. When controls are developed for some particular substance of interest, cotton dust for example, this approach would greatly simplify determination of whether feasible controls exist if permissible exposure limits are lowered.

6.4 ELIMINATING THE NEED FOR ENGINEERING CONTROLS

It is our observation that engineering controls in the form of ventilation systems and jerry-built enclosures can often be found about operations or processes which would not have required such "add-on" devices if they had been properly designed in the first place. An underlying concept in many of the recommendations made in this report has therefore involved the provision of that technology necessary for the design of processes which do not require such controls by virtue of the fact that they do not result in excessive exposures.

This concept can be found to particularly pervade the recommendations made in the "chemical processes" and "material handling" sections of this report. In both of these areas, there would appear to be significant opportunities for developing precisely the sort of technology

envisioned to be needed. Hence, it was suggested that the chemical process engineer be given the tools he needs to design a system which does not result in subsequent exposure problems. Without such tools, his new plant would probably end up with a series of exhaust fans placed in holes punched in the walls. Similarly, the test method for determining whether a material to be transported in some conveying system will present a dust hazard would permit mechanical engineers to weigh the costs of ventilated enclosures for belt conveyors against the additional costs to be incurred by specifying sealed screw conveyors. With today's costs of air cleaning equipment, ducting systems, and energy, elimination of the problem would probably be cheaper than attempting to control it.

This concept is presented here simply to allow its full appreciation. It is our belief that this sort of basic approach to developing "engineering controls" is the most correct one and that NIOSH should be alert to any and all future opportunities to support such research.

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APPENDIX A

SUMMARY OF USE/EXPOSURE DATA

FOR CHEMICALS IN SCP SETS

A THROUGH M

TABLE A-1. SUMMARY OF USE/EXPOSURE DATA FOR CHEMICALS
IN SCP SET A

Chemical	Acetone	Antimony	2-Butanone	Cyclohexanone	Hexone	Hydrogen Sulfide	Manganese	MDI	p-Nitroaniline	2-Pentanone									
Rubber production	X					X			X										
Spray-finishing	X		X	X	X					X									
Non-spray application	X		X	X	X			X		X									
Paint manufacture		X	X				X	X											
Cleaning and maintenance	X	X			X					X									
Wood pulping																			
Plastic & foam manufacture					X			X											
Pharmaceutical manufacture					X					X									
Cosmetic production										X									
Textile coating	X	X	X					X											
Pesticide application																			
Pesticide manufacture					X														
Ink production																			
Ink application				X															
Textile dyeing	X	X																	
Adhesive production and use	X		X		X					X									
Welding		X					X												
Abrasive machining		X																	
Dry cleaning																			
Aerosol production and use				X	X														
Electric equipment manufacture																			
Refrigerant use																			
Extractant or solvent use				X	X					X									
Chemical processes	X			X		X	X	X	X										
Mineral oil refining and dewaxing																			
Photographic film and chemical production																			
Artificial leather production																			
Safety glass production																			

Chemical Operation	Acetone	Anthracene	2-Butanone	Cyclohexanone	Hexone	Hydrogen Sulfide	Manganese	MDI	p-Nitroaniline	2-Pentanone									
Anesthetic use																			
Heat transfer fluid use																			
Mining operations		X				X	X												
Ceramics and glass production		X				X	X												
Petroleum refining			X			X													
Cleaning and degreasing	X		X	X															
Synthetic fiber manufacture	X					X													
Leather tanning and treatment						X													
Paint and varnish re- mover use					X														
Drying of paints, varnishes, etc.			X							X									
Detergent production							X												
Polishing compound production																			
Dye manufacture			X			X			X										
Fuel production																			
Lubricant manufacture and use									X										
Synthetic pine oil production																			
Perfume production																			
Food additive use																			
Smokeless powder production																			
Straw hat production																			
Fire extinguisher pro- duction and use																			
Water purification																			
Pyrotechnics and explo- sive making and use																			
Foundry operations		X					X												
Paper impregnation																			
Corrosion inhibitor making and use																			
Food processing																			
Ore refining and metal processing																			

TABLE A-2. SUMMARY OF USE/EXPOSURE DATA FOR CHEMICALS
IN SCP SET B

Chemical	Operation	Camphor	Chloroacetaldehyde	Alpha-Chloroacetophenone	Ethyl Butyl Ketone	Mesityl Oxide	Methyl (n-amy) Ketone	5-Methyl-2-Heptanone	Ozone	Pival											
	Rubber production																				
	Spray-finishing	X			X	X	X	X													
	Non-spray application	X			X																
	Paint manufacture	X				X	X														
	Cleaning and maintenance				X																
	Wood pulping																				
	Plastic & foam manufacture																				
	Pharmaceutical manufacture	X																			
	Cosmetic production																				
	Textile coating																				
	Pesticide application		X																		
	Pesticide manufacture																				
	Ink production																				
	Ink application																				
	Textile dyeing																				
	Adhesive production and use																				
	Welding																				
	Abrasive machining																				
	Dry cleaning																				
	Aerosol production and use			X																	
	Electric equipment manufacture																				
	Refrigerant use																				
	Extractions or solvent use																				
	Chemical processes	X	X	X		X		X													
	Mineral oil refining and dewaxing																				
	Photographic film and chemical production	X																			
	Artificial leather production																				
	Safety glass production																				

Chemical Operation	Camphor	Chloro- acetaldehyde	Alpha-Chloro- acetophenone	Ethyl Butyl Ketone	Mesityl Oxide	Methyl (n-amyl) Ketone	5-Methyl-3- Heptanone	Ozone	Pival												
Anesthetic use																					
Heat transfer fluid use																					
Mining operations					X																
Ceramics and glass production																					
Petroleum refining																					
Cleaning and degreasing					X																
Synthetic fiber manufacture																					
Leather tanning and treatment																					
Paint and varnish re- mover use					X																
Dying of paints, varnishes, etc.																					
Detergent production	X																				
Polishing compound production																					
Dye manufacture																					
Fuel production																					
Lubricant manufacture and use																					
Synthetic pine oil production																					
Perfume production	X																				
Food additive use																					
Smokeless powder production																					
Straw hat production																					
Fire extinguisher pro- duction and use																					
Water purification																					
Pyrotechnics and explo- sive making and use	X																				
Foundry operations																					
Paper impregnation																					
Corrosion inhibitor making and use																					
Food processing																					
Ore refining and metal processing																					

TABLE A-3. SUMMARY OF USE/EXPOSURE DATA FOR CHEMICALS
IN SCP SET C

Chemical	Acrolein	p-Tert- butyltoluene	Cumene	Cyclohexane	Diphenyl	Ethyl Benzene	Furfural	Alpha-Methyl Styrene	Styrene	Terphenyls	Vinyl Toluene								
Rubber production	X						X	X	X										
Spray-finishing			X			X		X	X	X	X								
Non-spray application			X	X		X		X	X	X	X								
Paint manufacture		X				X	X	X	X	X	X								
Cleaning and maintenance			X				X				X								
Wood pulping																			
Plastic & foam manufacture					X		X	X	X	X	X								
Pharmaceutical manufacture		X																	
Cosmetic production																			
Textile coating									X										
Pesticide application	X						X												
Pesticide manufacture																			
Ink production																			
Ink application																			
Textile dyeing																			
Adhesive production and use						X	X	X											
Welding																			
Abrasive machining	X																		
Dry cleaning																			
Aerosol production and use																			
Electric equipment manufacture																			
Refrigerant use																			
Extractant or solvent use			X	X															
Chemical processes	X	X	X	X	X	X	X	X	X	X	X								
Mineral oil refining and dewaxing							X												
Photographic film and chemical production																			
Artificial leather production																			
Safety Glass production																			

Operation	Acrolein	p-tert-Butyltoluene	Cumene	Cyclohexane	Diphenyl	Ethyl Benzene	Furfural	Alpha-Methyl Styrene	Styrene	Terphenyls	Vinyl Toluene							
Chemical																		
Anesthetic use																		
Heat transfer fluid use																		
Mining operations																		
Ceramics and glass production																		
Petroleum refining			X															
Cleaning and degreasing																		
Synthetic fiber manufacture																		
Leather tanning and treatment																		
Paint and varnish remover use							X											
Drying of paints, varnishes, etc.																		
Detergent production																		
Polishing compound production																		
Dye manufacture																		
Fuel production																		
Lubricant manufacture and use																		
Synthetic pine oil production																		
Perfume production																		
Food additive use																		
Smokeless powder production																		
Straw hat production																		
Fire extinguisher production and use																		
Water purification																		
Pyrotechnics and explosive making and use																		
Foundry operations																		
Paper impregnation																		
Corrosion inhibitor making and use																		
Food processing																		
Ore refining and metal processing																		

TABLE A-4. SUMMARY OF USE/EXPOSURE DATA FOR CHEMICALS
IN SCP SET D

Chemical	sec-Amyl Acetate	sec-Butyl Acetate	tert-Butyl Acetate	Butyl Acetate	Dibutyl phthalate	Diethyl phthalate	2-Ethoxyethyl acetate	Ethyl Acrylate	Ethyl Formate	sec-Hexyl Acetate	Isamyl Acetate	Isobutyl Acetate	Methyl Acetate	Methyl Acrylate	Methyl Cellulosolve Acetate	Methyl Methacrylate	di-sec-octyl phthalate	n-Propyl Acetate
Rubber production	X				X	X		X										
Spray-finishing	X		X		X	X			X									
Non-spray application	X				X				X	X								
Paint manufacture	X				X	X		X		X				X				
Cleaning and maintenance			X		X													
Wood pulping																		
Plastic & foam manufacture					X	X		X										
Pharmaceutical manufacture																		
Cosmetic production																		
Textile coating	X																	
Pesticide application									X									
Pesticide manufacture						X												
Ink production						X												
Ink application						X												
Textile dyeing						X												
Adhesive production and use					X	X								X				
Welding																		
Abrasive machining																		
Dry cleaning																		
Aerosol production and use			X															
Electric equipment manufacture																		
Refrigerant use																		
Extractant or solvent use																		
Chemical processes			X		X	X		X	X	X				X				
Mineral oil refining and dewaxing																		
Photographic film and chemical production																		
Artificial leather production									X									
Safety glass production									X									

Chemical	sec-Amyl acetate	sec-Butyl acetate	tert-Butyl acetate	Butyl acetate	Dibutyl phthalate	Dimethyl-phthalate	2-Ethoxy-ethyl acetate	Ethyl Acrylate	Ethyl Formate	sec-Hexyl Acetate	Isomyl Acetate	Isobutyl Acetate	Methyl Acetate	Methyl Acrylate	Methyl Cellulosive Acetate	Methyl Methacrylate	di-sec-octyl phthalate	n-Propyl Acetate
Operation																		
Anesthetic use																		
Heat transfer fluid use																		
Mining operations																		
Ceramics and glass production																		
Petroleum refining																		
Cleaning and degreasing																		
Synthetic fiber manufacture																		
Leather tanning and treatment																		
Paint and varnish remover use																		
Drying of paints, varnishes, etc.																		
Detergent production																		
Polishing compound production																		
Dye manufacture																		
Fuel production																		
Lubricant manufacture and use																		
Synthetic pine oil production																		
Perfume production																		
Food additive use																		
Smokeless powder production																		
Straw hat production																		
Fire extinguisher production and use																		
Water purification																		
Pyrotechnics and explosive making and use																		
Foundry operations																		
Paper impregnation																		
Corrosion inhibitor making and use																		
Food processing																		
Ore refining and metal processing																		

TABLE A-5. SUMMARY OF USE/EXPOSURE DATA FOR CHEMICALS IN SCP SET E

Chemical	Allyl Alcohol	n-Amyl Acetate	sec-Butyl Alcohol	tert-Butyl Alcohol	Butyl Alcohol	Cyclohexanol	Diacetone Alcohol	Ethyl Acetate	Ethyl Alcohol	Hydroquinone	Isomyl Alcohol	Isobutyl Alcohol	Isopropyl Acetate	Isopropyl Alcohol	Methyl Alcohol	Methyl Isobutyl Carbinol	Propyl Alcohol
Operation																	
Rubber production					X				X						X		
Spray-finishing		X									X						
Non-spray application		X	X	X	X	X	X	X	X		X	X	X	X	X	X	X
Paint manufacture		X	X	X	X				X		X	X	X	X			X
Cleaning and maintenance		X							X		X		X	X			
Wood pulping																	
Plastic & foam manufacture		X						X				X	X		X		
Pharmaceutical manufacture	X	X	X					X	X		X				X	X	X
Cosmetic production									X								
Textile coating		X					X		X				X	X	X		
Pesticide application	X																
Pesticide manufacture																	
Ink production		X					X		X				X	X	X		
Ink application		X					X	X	X		X		X	X	X		X
Textile dyeing							X			X				X			X
Adhesive production and use		X			X				X					X			X
Welding																	
Abrasive machining																	
Dry cleaning																	
Aerosol production and use		X						X									
Electric equipment manufacture																	
Refrigerant use																	
Extractant or solvent use		X		X			X				X		X	X	X	X	X
Chemical processes	X	X	X	X	X	X			X		X	X	X	X	X	X	X
Mineral oil refining and dewaxing	X																
Photographic film and chemical production		X			X		X	X	X	X	X					X	
Artificial leather production							X	X	X	X							
Safety glass production					X												X

Chemical Operation	Allyl Alcohol	n-Amyl Acetate	sec-Butyl Alcohol	tert-Butyl Alcohol	Butyl Alcohol	Cyclohexanol	Diacetone Alcohol	Ethyl Acetate	Ethyl Alcohol	Hydroquinone	Isoamyl Alcohol	Isobutyl Alcohol	Isopropyl Acetate	Isopropyl Alcohol	Methyl Alcohol	Methyl Isobutyl Carbinol	Propyl Alcohol
Anesthetic use																	
Heat transfer fluid use																	
Mining operations											X					X	
Ceramics and glass production																	
Petroleum refining																	
Cleaning and degreasing			X	X	X	X								X			X
Synthetic fiber manufacture			X	X	X	X								X			X
Leather tanning and treatment					X												X
Paint and varnish re-mover use			X					X							X		
Drying of paints, varnishes, etc.			X														
Detergent production						X								X			X
Polishing compound production		X															X
Dye manufacture			X					X						X			X
Fuel production														X			
Lubricant manufacture and use																	
Synthetic pine oil production												X				X	
Perfume production	X		X	X	X						X		X				
Food additive use		X															
Smokeless powder production													X				
Straw hat production		X															
Fire extinguisher production and use																	
Water purification																	
Pyrotechnics and explosive making and use																	
Foundry operations																	
Paper impregnation																	
Corrosion inhibitor making and use																	
Food processing																	
Ore refining and metal processing																	

TABLE A-6. SUMMARY OF USE/EXPOSURE DATA FOR CHEMICALS
IN SCP SET F

Chemical	2-Butoxy- Ethanol	n-Butyl Glycidyl Ether	Chlorinated Camphene	Cyclohexene	Cyclopenta- diene	Diglycidyl Ether	Dipropylene Ether	Ethyl Ether	Glycidol	Isopropyl Glycidyl Ether	Methyl Acrylate	Methyl Cellulosate	Methylal	Phenyl Ether Vapor	Phenyl Ether-Bl- Mixture	Phenyl Glycidyl Ether	Propylene Oxide	Tetrahydro- furan
Operation																		
Rubber production																		
Spray-finishing	X											X						
Non-spray application	X																	
Paint manufacture					X		X		X									
Cleaning and maintenance				X			X		X									
Wood pulping																		
Plastic & foam manufacture					X				X									
Pharmaceutical manufacture								X										
Cosmetic production																		
Textile coating							X											
Pesticide application																		
Pesticide application			X															
Pesticide manufacture			X															
Ink production	X																	
Ink application							X											
Textile dyeing																		
Adhesive production and use									X									
Welding																		
Abrasive machining											X							
Dry cleaning																		
Aerosol production and use																		
Electric equipment manufacture																		
Refrigerant use																		
Extractant or solvent use	X						X											
Chemical processes	X			X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Mineral oil refining and dewaxing																		
Photographic film and chemical production																		
Artificial leather production																		
Safety glass production																		

Chemical	2-butoxy-ethanol	n-butyl ether	chlorinated camphene	cyclohexene	cyclopentadiene	diglycidyl ether	dipropylene glycol methyl ether	ether	ethyl ether	glycidol	isopropyl glycidyl ether	methyl acrylate	methyl cellosolve	methylal	phenyl ether vapor	phenyl ether-bi-mixture	phenyl glycidyl ether	propylene oxide	tetrahydrofuran
Anesthetic use									X										
Heat transfer fluid use							X								X				
Mining operations																			
Ceramics and glass production																			
Petroleum refining																			
Cleaning and degreasing																			
Synthetic fiber manufacture																			
Leather tanning and treatment							X												
Paint and varnish re-mover use																			
Drying of paints, varnishes, etc.					X														
Detergent production	X																	X	
Polishing compound production							X												
Dye manufacture							X		X										
Fuel production													X						X
Lubricant manufacture and use																			
Synthetic pine oil production					X														
Perfume production									X										X
Food additive use																			
Smokeless powder production							X		X										X
Straw hat production																			
Fire extinguisher production and use																			
Water purification																			
Pyrotechnics and explosive making and use																			
Foundry operations																			
Paper impregnation																			
Corrosion inhibitor making and use																			
Food processing																			
Ore refining and metal processing																			

TABLE A-7. SUMMARY OF USE/EXPOSURE DATA FOR CHEMICALS
IN SCP SET C

Chemical	Butadiene	Dioxane	Heptane	Hexane	Ketene	LPG	MAPP	Methyl Cyclohexane	Coal Tar Naphtha	Octachloro- naphthalene	Octane	Pentachloro- naphthalene	Pentane	Petroleum Naphtha	Propane	Propylene Dichloride	Stoddard Solvent	Turpentine
Operation																		
Rubber production	X					X		X								X	X	
Spray-finishing		X	X					X						X			X	X
Non-spray application		X	X	X				X						X			X	X
Paint manufacture		X	X	X	X	X			X		X			X			X	X
Cleaning and maintenance		X	X	X				X		X	X	X	X		X		X	
Wood pulping		X																
Plastic & foam manufacture			X	X	X						X							
Pharmaceutical manufacture		X		X	X													
Cosmetic production		X																
Textile coating									X	X				X			X	
Pesticide application	X								X	X		X		X			X	
Pesticide manufacture									X							X	X	
Ink production			X	X					X		X						X	X
Ink application			X	X					X								X	
Textile dyeing		X																
Adhesive production and use		X	X	X					X									
Welding							X											
Abrasive machining						X	X											
Dry cleaning														X			X	
Aerosol production and use						X									X		X	
Electric equipment manufacture										X								
Refrigerant use															X			
Extractant or solvent use			X	X	X			X						X	X	X		
Chemical processes	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Mineral oil refining and desasing																		
Photographic film and chemical production																		
Artificial leather Production																		
Safety Glass production																		

Chemical	Butadiene	Dioxane	Heptane	Hexane	Ketene	LPG	MAPP	Methyl Cyclohexane	Coal Tar Naphtha	Octachloro-naphthalene	Octane	Pentachloro-naphthalene	Pentane	Petroleum Naphtha	Propane	Propylene Dichloride	Stoddard Solvent	Turpentine
Operation																		
Anesthetic use																		
Heat transfer fluid use																		
Mining operations													X					
Ceramics and Glass production																		
Petroleum refining			X															
Cleaning and degreasing		X	X					X										
Synthetic fiber manufacture																		
Leather tanning and treatment	X																	
Paint and varnish remover use		X														X		
Drying of paints, varnishes, etc.		X																
Detergent production		X									X							
Polishing compound production		X																X
Dye manufacture					X													
Fuel production						X												
Lubricant manufacture and use											X				X			
Synthetic pine oil production										X		X						X
Perfume production																		X
Food additive use																		
Smokeless powder production																		
Straw hat production																		
Fire extinguisher production and use																		
Water purification																		
Pyrotechnics and explosive making and use																		
Foundry operations																		
Paper impregnation																		
Corrosion inhibitor making and use																		
Food processing																		
Ore refining and metal processing																		

TABLE A-8. SUMMARY OF USE/EXPOSURE DATA FOR CHEMICALS
IN SCP SET H

Chemical	Benzyl Chloride	Bromoform	Chlorobromomethane	Chloroprene	Dichlorodifluoromethane	1,2-Dichloroethane	Dichloromethane	Dichlorotetrafluoroethane	Difluoromethane	Dibromomethane	Ethyl Bromide	Ethyl Chloride	Ethylene Chlorohydrin	Ethylene Dibromide	Fluorotrifluoromethane	Hexachloroethane	Hexachloronaphthalene	Methyl Chloride	Methyl Iodide
Rubber production	X	X		X		X										X		X	
Spray-finishing																			
Non-spray application																			
Paint manufacture				X		X										X			
Cleaning and maintenance		X	X	X	X	X	X	X	X	X	X						X		X
Wood pulping																			
Plastic & foam manufacture					X	X	X	X	X	X					X			X	
Pharmaceutical manufacture		X								X	X	X	X	X				X	X
Cosmetic production																			
Textile coating		X		X										X					
Pesticide application	X		X							X	X	X	X	X	X			X	X
Pesticide manufacture	X		X	X		X									X			X	
Ink production																			
Ink application																			
Textile dyeing	X					X													
Adhesive production and use																			
Welding																			
Abrasive machining																	X		
Dry cleaning																			
Aerosol production and use					X		X	X	X			X			X			X	
Electric equipment manufacture	X																X		
Refrigerant use					X		X	X	X	X	X	X	X	X	X			X	
Extractant or solvent use		X			X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Chemical processes	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Mineral oil refining and dewaxing																			
Photographic film and chemical production																			
Artificial leather production																			
Safety glass production																			

Chemical Operation	Benzyl Chloride	Bromoform	Chlorobromomethane	Chloroprene	Dichlorodifluoro- methane	1,2-Dichloro- ethylene	Dichloromono- fluoroethane	Dichlorotetra- fluoroethane	Difluoro- dibromomethane	Ethyl Bromide	Ethyl Chloride	Ethylene Chlorohydrin	Ethylene Dibromide	Fluorochloro- ethane	Hexachloro- ethane	Hexachloro- naphthalene	Methyl Chloride	Methyl Iodide
Anesthetic use										X	X							
Heat transfer fluid use					X			X										
Mining operations		X																
Ceramics and glass production																		
Petroleum refining																	X	
Cleaning and degreasing												X						
Synthetic fiber manufacture																		
Leather tanning and treatment																		
Paint and varnish re- mover use																		
Drying of paints, varnishes, etc.																		
Detergent production	X																	
Polishing compound production																		
Dye manufacture										X	X	X					X	
Fuel production													X					
Lubricant manufacture and use	X														X	X		
Synthetic pine oil production															X	X		
Perfume production										X	X						X	
Food additive use																		
Smokeless powder production																		
Straw hat production																		
Fire extinguisher pro- duction and use			X		X			X	X						X			
Water purification							X											
Pyrotechnics and explo- sive making and use																		
Foundry operations																		
Paper impregnation																		
Corrosion inhibitor packaging and use																		
Food processing																		
Ore refining and metal processing																		

TABLE A-9. SUMMARY OF USE/EXPOSURE DATA FOR CHEMICALS
IN SCP SET I

Chemical	Acetylene Tetrabromide	Allyl Chloride	Chlorinated Diphenyl Oxide	Chlorobenzene	Chlorodiphenyl, 42% chlorine	Chlorodiphenyl, 54% chlorine	1,3-Dichloro-5,5 Dimethylhydantoin	1,1-Dichloroethane	Epi-chlorohydrin	1,1,1,2-Tetrahydro 1,2-Difluoroethane	1,1,1,2-Tetrahydro 2,2-Difluoroethane	1,1,2-Trichloro-1,2 naphthalene	1,1,2-Trichloro-1,2 naphthalene	Trichloro- naphthalene	1,2,3-Trichloro- propane	Trifluoromono- Bromomethane
Operation																
Rubber production	X			X				X								
Spray-finishings				X	X											
Non-spray application				X												
Paint manufacture				X	X											
Cleaning and maintenance	X				X					X					X	
Wood pulping																
Plastic & foam manufacture	X				X				X							X
Pharmaceutical manufacture		X		X					X							
Cosmetic production				X												
Textile coating					X											
Pesticide application					X											
Pesticide manufacture			X		X			X								
Ink production				X	X				X							
Ink application				X	X											
Textile dyeing				X	X											
Adhesive production and use				X	X				X				X			
Welding				X	X											
Abrasive machining					X									X		
DRY cleaning																
Aerosol production and use										X						
Electric equipment manufacture			X		X											
Refrigerant use					X											
Extractant or solvent use				X												X
Chemical processes	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X
Mineral oil refining and desaxing																
Photographic film and chemical production																
Artificial leather production																
Safety glass production																

Chemical	Operation	Acetylene Tetrahydride	Allyl Chloride	Chlorinated Diphenyl Oxide	Chlorobenzene	Chlorodiphenyl, 42% chlorine	Chlorodiphenyl, 54% chlorine	1,3-Dichloro-5,5- dimethylhydantoin	1,1-Dichloroethane	Epichlorohydrin	1,1,2-Tetrachloro- 1,2-Difluoroethane	1,1,1,2-Tetrachloro- 1,2-Difluoroethane	1,1,2-Tetra- chloroethane	Tetrachloro- naphthalene	1,1,1,2-Trichloro-1,2, 2-trifluoroethane	Trichloro- naphthalene	1,2,3-Trichloro- propane	Trifluoromono- propane
Anesthetic use																		
Heat transfer fluid use																		
Mining operations																		
Ceramics and glass production		X																
Petroleum refining																		
Cleaning and degreasing																		
Synthetic fiber manufacture																		
Leather tanning and treatment																		
Paint and varnish re- mover use																		
Drying of paints, varnishes, etc.																		
Detergent production																		
Polishing compound production																		
Dye manufacture																		
Fuel production																		
Lubricant manufacture and use																		
Synthetic pine oil production																		
Perfume production																		
Food additive use																		
Smokeless powder production																		
Straw hat production																		
Fire extinguisher pro- duction and use																		
Water purification																		
Pyrotechnics and explo- sive making and use																		
Foundry operations																		
Paper impregnation																		
Corrosion inhibitor making and use																		
Food processing																		
Ore refining and metal processing																		

TABLE A-10. SUMMARY OF USE/EXPOSURE DATA FOR CHEMICALS
IN SCP SET J

Chemical	Bucylamine	Carbon Tetrachloride	Chloroform	Diazomethane	o-Dichlorobenzene	Diethylamine	Diethylamino Ethanol	Diisopropylamine	Dimethylamine	Ethanolamine	Ethylene Dichloride	Methyl Bromide	Methyl Chloroform	Methylene Chloride	Phosgene	Tetrachloroethylene	1,1,2-Trichloroethane	Trichloroethylene
Rubber production	X								X									X
Spray-finishing					X													X
Non-spray application					X													X
Paint manufacture			X		X		X				X		X					X
Cleaning and maintenance	X	X	X	X	X	X		X	X	X	X		X			X		X
Wood pulping																		
Plastic & foam manufacture	X		X			X	X		X					X				
Pharmaceutical manufacture			X		X	X	X		X				X					X
Cosmetic production								X										
Textile coating						X	X											
Pesticide application	X	X	X		X						X	X				X		X
Pesticide manufacture	X				X	X	X	X	X				X					
Ink production													X					X
Ink application																		X
Textile dyeing																		X
Adhesive production and use					X		X						X	X		X		X
Welding		X									X		X	X		X		X
Abrasive machining															X			
Dry cleaning			X		X													X
Aerosol production and use													X	X		X		X
Electric equipment manufacture		X											X	X				
Refrigerant use															X			
Extractant or solvent use		X	X		X						X	X	X	X		X		X
Chemical processes	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Mineral oil refining and dewaxing																		
Photographic film and chemical production							X											
Artificial leather production									X									
Safety glass production																		

Chemical Operation	Butylamine	Carbon Tetrachloride	Chloroform	Diazomethane	O-Dichloro- benzene	Diethylamine	Diethylamino Ethanol	Diisopropylamine	Dimethylamine	Ethanolamine	Ethylene Dichloride	Methyl Bromide	Methyl Chloroform	Methylene Chloride	Phosgene	Tetrachloro- ethylene	1,1,2-Trichloro- ethane	Trichloro- ethylene
Anesthetic use			X															X
Heat transfer fluid use			X		X											X		
Mining operations								X										
Ceramics and glass production																		
Petroleum refining																		
Cleaning and degreasing					X													X
Synthetic fiber manufacture									X									
Leather tanning and treatment					X				X									
Paint and varnish re- mover use					X				X									X
Drying of paints, varnishes, etc.																		
Detergent production	X				X	X			X	X								
Polishing compound production					X		X			X								X
Dye manufacture	X		X		X	X			X				X					
Fuel production																		
Lubricant manufacture and use						X	X		X									X
Synthetic pine oil production													X					
Perfume production																		
Food additive use																		
Smokeless powder production																		
Straw hat production																		
Fire extinguisher pro- duction and use																		
Water purification																		
Pyrotechnics and explo- sive making and use																		
Foundry operations																		
Paper impregnation																		
Corrosion inhibitor making and use																		
Food processing																		
Ore refining and metal processing																		

TABLE A-11. SUMMARY OF USE/EXPOSURE DATA FOR CHEMICALS
IN SCP SET K

Chemical	Acrylamide	Acrylonitrile	2-Aminopyridine	Aniline	OCBM	1,1-Dimethyl Hydrazine	Ethylamine	Ethylendiamine	n-Ethyl Morpholine	Isopropylamine	Methylamine	Monomethylamine	Monomethyl Hydrazine	Morpholine	p-phenylene diamine	Propylene imine	Tetramethyl succinonitrile	Triethylamine	
Rubber production				X		X	X	X		X	X				X				
Spray-finishing																			
Non-spray application																			
Paint manufacture		X				X													X
Cleaning and maintenance	X	X	X		X	X	X		X	X	X		X		X	X			
Wood pulping	X							X											
Plastic & foam manufacture		X		X		X	X	X	X	X			X				X		X
Pharmaceutical manufacture		X	X	X		X	X	X	X	X	X		X	X	X	X			X
Cosmetic production																			
Textile coating	X	X				X	X	X											X
Pesticide application		X	X				X												
Pesticide manufacture		X		X			X	X		X	X		X	X					X
Ink production																			X
Ink application									X										X
Textile dyeing	X			X											X				
Adhesive production and use	X			X			X	X											
Welding																			
Abrasive machining																			
Dry cleaning																			
Aerosol production and use																			
Electric equipment manufacture																			
Refrigerant use																			
Extractant or solvent usage							X	X	X	X	X		X	X	X	X	X	X	X
Chemical processes	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Mineral oil refining and dewaxing																			
Photographic film and chemical production	X			X		X													X
Artificial leather production																			
Safety glass production																			

Chemical	Acrylamide	Acrylonitrile	2-Aminopyridine	Aniline	OCBM	1,1-Dimethyl Hydrazine	Ethylamine	Ethylenediamine	n-Ethyl Morpholine	Isopropylamine	Methylamine	Monomethylamine	Monomethylhydrazine	Morpholine	p-Phenylene diamine	Propylene Imine	Tetramethyl Succinonitrile	Triethylamine		
Anesthetic use																				
Heat transfer fluid use																				
Mining operations	X																			
Ceramics and glass production						X														
Petroleum refining						X														
Cleaning and degreasing								X												
Synthetic fiber manufacture	X	X		X																
Leather tanning and treatment									X											
Paint and varnish re-mover use										X										
Drying of paints, varnishes, etc.																				
Detergent production																				
Polishing compound production																				
Dye manufacture		X	X	X		X	X	X	X	X	X	X								
Fuel production	X																			
Lubricant manufacture and use	X		X			X														
Synthetic pine oil production																				
Perfume production																				
Food additive use				X																
Smokeless powder production																				
Straw hat production																				
Fire extinguisher production and use																				
Water purification	X							X												
Pyrotechnics and explosive making and use																				
Foundry operations											X									
Paper impregnation																				
Corrosion inhibitor making and use				X		X	X	X												
Food processing																				
Ore refining and metal processing																				

TABLE A-12. SUMMARY OF USE/EXPOSURE DATA FOR CHEMICALS
IN SCP SET L

Chemical	Acetic Acid	Acetic Anhydride	Acetonitrile	Allyl propyl disulfide	Antidine	Cresol	Dimethylaniline	Dinitro-o-cresol	Formic Acid	Hydrogen Fluoride	Oxalic Acid	Phenol	Phenylhydrazine	Pyridine	Sulfuric Acid	o-Toluidine	Xylidine
Rubber production	X					X			X				X		X	X	X
Spray-finishing																	
Non-spray application																	
Paint manufacture	X	X															
Cleaning and maintenance	X	X	X		X	X	X	X	X	X	X				X	X	X
Wood pulping																	
Plastic & foam manufacture	X	X	X			X				X	X	X	X		X	X	X
Pharmaceutical manufacture	X	X	X			X	X		X	X	X	X	X	X	X		X
Cosmetic production																	
Textile coating															X		
Pesticide application								X									
Pesticide manufacture									X		X		X		X	X	
Ink production			X			X			X								
Ink application						X											
Textile dyeing						X											
Adhesive production and use		X			X	X			X			X					
Welding	X						X						X				
Abrasive machining																	
Dry cleaning												X					
Aerosol production and use	X									X	X						
Electric equipment manufacture											X						
Refrigerant use									X	X	X						
Extractant or solvent use	X								X	X	X	X					
Chemical processes	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X
Mineral oil refining and desaxing													X				
Photographic film and chemical production	X	X				X				X		X	X	X			
Artificial leather production																	
Safety glass production																	

Chemical Operation	Acetic Acid	Acetic Anhydride	Acetonitrile	Allyl propyl disulfide	Anisidine	Cresol	Dimethylamine	Dinitro-o-cresol	Formic Acid	Hydrogen Fluoride	Oxalic Acid	Phenol	Phenylhydrazine	Pyridine	Sulfuric Acid	o-Toluidine	Xylidine
Anesthetic use																	
Heat transfer fluid use											X					X	
Mining operations						X					X						
Ceramics and glass production											X		X			X	
Petroleum refining											X	X	X			X	
Cleaning and degreasing									X				X			X	
Synthetic fiber manufacture	X	X	X													X	
Leather tanning and treatment	X								X			X					
Paint and varnish re- mover use																	
Drying of paints, varnishes, etc.											X					X	
Detergent production			X			X											
Polishing compound production											X			X	X	X	X
Dye manufacture	X		X								X				X		X
Fuel production													X				
Lubricant manufacture and use						X	X										
Synthetic pine oil production																	
Perfume production		X	X			X							X				
Food additive use	X					X			X			X					
Smokeless powder production																	
Straw hat production																	
Fire extinguisher pro- duction and use										X							
Water purification																	
Pyrotechnics and explo- sive making and use		X				X	X							X	X	X	
Foundry operations											X		X				
Paper impregnation																	
Corrosion inhibitor making and use																	
Food processing				X													X
Ore refining and metal processing																	

TABLE A-13. SUMMARY OF USE/EXPOSURE DATA FOR CHEMICALS
IN SCP SET M

Chemical Operation	Copper Dusts & Mists	Crystalline Silica	Hafnium	2-Hexanone	Maleic Anhydride	Molybdenum Soluble Compounds	Osmium Tetraoxide	Phosphoric Acid	Phosphorus, yellow	Phthalic Anhydride	Platinum Soluble Salt	Quinone	Rhodium	Selenium	Tellurium Hexafluoride	Tin (organic compounds)	Zirconium
Rubber production					X			X						X			
Spray-finishing																	
Non-spray application																	
Paint manufacture	X			X	X	X											
Cleaning and maintenance	X			X	X				X	X	X	X				X	
Hood pulping																	
Plastic & foam manufacture					X	X				X		X				X	
Pharmaceutical manufacture					X			X		X		X				X	X
Cosmetic production	X																
Textile coating	X				X												
Pesticide application																	
Pesticide manufacture					X	X			X			X				X	
Ink production					X	X											
Ink application					X	X				X							
Textile dyeing																	
Adhesive production and use					X			X									
Welding	X																
Abrasive machining X																	
Dry cleaning																	
Aerosol production and use																	
Electric equipment manufacture													X	X			X
Refrigerant use																	
Extractant or solvent use				X													
Chemical processes	X			X	X	X	X	X	X	X	X	X	X	X	X	X	X
Mineral oil refining and dewaxing	X																
Photographic film and chemical production					X	X	X	X			X	X					
Artificial leather production																	
Safety glass production																	

Chemical	Copper & Mats	Crotonaldehyde	Haftum	2-Hexanone	Maleic Anhydride	Molybdenum Soluble Compounds	Osmium Tetraoxide	Phosphoric Acid	Phosphorus, yellow	Phthalic Anhydride	Platinum Soluble Salt	Quinone	Rhodium	Selenium	Tellurium Hexafluoride	Tin (organic compounds)	Zirconium
Anesthetic use																	
Heat transfer fluid use																	
Mining operations																	
Ceramics and glass production					X	X		X						X		X	
Petroleum refining						X											
Cleaning and degreasing								X									
Synthetic fiber manufacture					X												
Leather tanning and treatment		X			X	X										X	
Paint and varnish re-mover use																	
Drying of paints, varnishes, etc.						X											
Detergent production					X			X						X			
Polishing compound production						X				X						X	
Dye manufacture	X				X											X	
Fuel production																	
Lubricant manufacture and use	X				X									X	X		
Synthetic pine oil production																	
Perfume production										X							
Food additive use								X						X			
Smokeless powder production																	
Straw hat production																	
Fire extinguisher production and use																	
Water purification																	
Pyrotechnics and explosive making and use									X					X		X	
Foundry operations														X		X	
Paper impregnation																	
Corrosion inhibitor making and use		X				X											
Food processing					X												
Ore refining and metal processing	X		X			X	X	X	X		X		X	X			X

