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The Impact of Maintenance and Design for Ventilation Systems

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Ventilation systems need to be designed to include access for cleaning and preventive maintenance. Without such access, the exhaust volume will deteriorate. Because of access difficulties and the many demands on their time, plant managers are sometimes errant in performing proper preventive maintenance. Three surveys measuring workers' exposures to methylene chloride were conducted at the same furniture stripping facility. A new ventilation system was installed for the first survey, resulting in an exhaust volume of 2900 cfm and worker exposure to methylene chloride of 59 ppm (geometric mean). Immediately after the first survey, the gasoline-powered fan was replaced by a smaller capacity electrically powered fan. Deterioration in the ventilation system was seen after seven years. Problems included clogged slots, paint chips and sawdust deposits in plenums, and a loose and frayed fan belt. The second survey indicated a reduction in exhaust volume to 1060 cfm and increased worker exposure to 330 ppm. With the smaller capacity fan still in place, the system was otherwise upgraded to allow for easier access and maintenance was performed. The third survey showed that the ventilation system performance was better (exhaust volume improved to 2080 cfm) and the worker exposures were reduced to 73 ppm. This study shows the benefits of designing for preventive maintenance and the necessity of keeping the ventilation systems clean.

Keywords Methylene Chloride, Dip Tank, Furniture Stripping, Maintenance, Small Business, Occupation, Ventilation, Engineering, SIC 7641

Preventive maintenance is an important task for all ventilation systems. The Environmental Protection Agency (EPA) and the National Institute for Occupational Safety and Health (NIOSH)[1] recommend a preventive maintenance plan for heating, ventilation, and air conditioning (HVAC) equipment and conclude that many companies generally delay it as long as possible. EPA and NIOSH recommend the following for a preventive maintenance plan: periodic inspection, cleaning, and service; adjustment and calibration of control system components; and selection of good quality maintenance equipment and replacement parts.

The American Society of Heating, Refrigeration, and Air-Conditioning Engineers[2] (ASHRAE) recommends that HVAC systems be regularly maintained and serviced. ASHRAE recommends that records be kept of all work performed on ventilation systems, and that systems be periodically retested to measure actual performance. Any discrepancies between designed and actual performance indicate a requirement to review the system.

The American Conference of Governmental Industrial Hygienists (ACGIH)®[3] recommends that fans be maintained by checking that fan rotation has not been inadvertently reversed. Other items to check include bearings, excessive vibration, and belt drives for proper tension and minimum wear.

Guffey et al.[4] studied newly installed ventilation systems over one year and found that required maintenance was not performed. In the study, three ventilation systems were installed, two of which were initially installed incorrectly and did not meet minimum design specifications. Components that would have aided in the preventive maintenance of the ventilation systems such as cleanouts and enclosures to gather dust were not installed. Cleaning of the ventilation systems was not seen as important by management and was not conducted. The investigators performed some cleaning of the ventilation systems themselves and found branch ducts that were blocked (with reduced flow rate of up to 90%). They reported the following design characteristics that would help aid in preventive maintenance: provide cleanouts so that ducts do not have to be completely disassembled for cleaning and do not use sheet metal screws because, when cleaning, screws inadvertently catch rags and pull them in. They found that cleaning of duct work should be performed on a weekly basis for grinders in a hard metal resharpening shop.

Jackson[5] recommended that ventilation systems be monitored for these reasons: to maintain maximum performance, to ensure that a system complies with design specifications or codes, to determine whether the system can be expanded, or to evaluate whether a similar future system should have extra capacity. Jackson offered that, "In most industries, dust will accumulate on the inside of surfaces of the duct causing a reduction in the air volume flow rate."[5] He further suggested that systems should be checked every three months for the first year until records are available to indicate the frequency of cleaning required.

Symanski et al.[6] evaluated long-term trends in exposures to nickel aerosols. As part of an investigation of 10 facilities over many years, they noted the presence of local exhaust ventilation systems. Although most exposures (71%) to nickel aerosols decreased with time, exposures at those facilities using local exhaust systems increased over time. The authors did not have data of specific control measures. It could be hypothesized that lack of preventive maintenance could be part of the cause of the increased exposures at facilities using local exhaust systems.

The goal of this article is to emphasize the importance and provide a specific example of preventive maintenance during the design of industrial ventilation systems. This article reports on the design and maintenance of a ventilation system at one facility over seven years.

BACKGROUND

Three surveys were conducted at a furniture stripping shop located in Ohio with less than 10 employees. This facility used the "dip tank method" to strip furniture. Paint, varnish, and stain coatings were stripped by dipping furniture in an open tank containing the stripping solution. After the item was dipped, the worker leaned over the stripping tank and scrubbed the furniture to remove the finish from the crevices. The worker then transported the furniture to an unventilated rinse area where a high pressure water system was used to rinse the furniture. The furniture was then moved to an adjacent area to dry without the benefit of local exhaust.

A survey was conducted in 1991[7] after new ventilation controls were installed on a furniture stripping dip tank. Shortly thereafter, the ventilation system fan was replaced with a smaller fan by the shop owner. A second survey was conducted in March 1998 with few other changes to the ventilation system except those caused by neglect over time—wear and deterioration.[8] A third survey was conducted in June 1998 after the ventilation system was cleaned and upgraded.

Furniture stripping solution is typically composed of 50–70 percent methylene chloride. Methylene chloride is listed as a potential occupational carcinogen by NIOSH.[9] Overexposure to methylene chloride while stripping furniture may potentially cause death due to asphyxiation; one such incident was reported in 1999.[10] The Occupational Safety and Health Administration (OSHA) permissible exposure limit (PEL) for methylene chloride was reduced from 500 to 25 ppm over an 8-hour day.[11,12]

METHODS

For each survey, air samples were collected in the worker's breathing zone during stripping and rinsing tasks. Two workers alternated the stripping and rinsing tasks concurrently during the first survey. For the second and third surveys, one worker exclusively conducted the furniture stripping, alternating about equally between the stripping and rinsing tasks. Area samples were collected near the stripping tank and near the rinsing area, except during the second survey which lacked stripping area samples. Survey one consisted of ten two-hour runs over three days, survey two consisted of three one-hour runs on one day, and survey three consisted of four one-hour runs on one day. Area and personal breathing zone samples were collected simultaneously. No short-term samples were collected.

Air samples for methylene chloride were collected using NIOSH method 1005[13] and OSHA method 80[14] side by side, except during the first survey when only NIOSH method 1005 was used. Samples analyzed using NIOSH method 1005 were collected on two 100/50 mg charcoal tubes (SKC) in series at a flow rate of 0.02 liters per minute (Lpm) using a personal sampling pump. Samples analyzed using OSHA method 80 were collected on one carbosieve S-III (ORBO 91, Supelco, Inc., Bellefonte, PA) sorbent sampling tube with a flow rate of 0.05 Lpm using a personal sampling pump.

The average slot velocity for the stripping tank ventilation system was recorded by measuring air velocity with a Velocicalc (T.S.I., Model 8386A, St. Paul, MN) velometer at eight evenly spaced locations across each slot. The total exhaust volume of the stripping tank ventilation system was measured in the discharge duct at eight duct diameters above the nearest disturbance using a ten-point pitot traverse method[3] with a digital micromanometer (Air Neotronics, Model MP20SR, Oxford, England, or Dwyer Model 400). Static pressure was measured during the second and third surveys at the same location as the pitot traverse. Doors to the facility were opened to allow for make-up air to supply the ventilation systems during the first and third surveys. During the second survey, when doors to the facility were closed, the amount of force required to close a 20 sq ft door was measured with a force gage (Model FDV50, Wager Digital Force Gage) to estimate the air pressure in the shop.

Bulk samples of the stripping solution were collected for determining methylene chloride percentage by weight for the first and third survey.

Hood Design

The ventilation system for the stripping tank that was installed for the first survey consisted of a slotted hood ventilation system. The design for this system was based on ACGIH criteria established for surface tanks (VS-70-02).[3] For more detailed information about the original design see Hall.[7] A plenum was attached to the front end of the tank and to the slot hoods (3/4″ slot width) on each side of the tank to obtain an even air flow distribution. A 12-inch diameter duct from the center of the front plenum passed through an exterior wall into a fan located outside. A portable, gasoline-powered fan (8 HP, gas engine, 15-1/8″ diameter centrifugal fan, Coppus Model TE-6) was used for drawing air through the ventilation system.

During the second survey, the same basic ventilation system existed except that an electrical fan (2 HP, single phase, 230 volt 16-1/8″ diameter centrifugal fan, Dayton Model 3C495) had replaced the gasoline-powered fan and a weather cap had been installed. The 8 HP, gas-powered fan used during the initial survey was for test purposes only. When the facility had to purchase an electrical fan it was discovered that a 2 HP fan was the largest that could be supported by the existing single-phase electrical system. Cost to upgrade the electrical system was prohibitive. This 2 HP fan would enable a flow rate of about 1900 cfm if the change in fan was the only change to occur.

Observations during the second survey indicated that the ventilation system had deteriorated. The slots were clogged with paint and varnish buildup (Figure 1); the T-duct immediately following the fan had deteriorated from rust; and the front and back plenums for the stripping tank exhaust were found to have as much as nine inches of paint chips, sawdust, and other debris in the bottom (Figure 2). Also, a weather cap resulted in additional pressure loss (0.08″ less than a vertical discharge cap) that was not foreseen in the design (Figure 3). All doors to the facility were closed during this survey because it was winter; therefore, fresh air entering the building was limited to infiltration through cracks around windows and doors.

The dip tank ventilation system was modified before the third survey to rectify the problems with the system. The exhaust plenums were cut out and hinges were added near the slots so that they could be opened for cleaning (Figure 4); two 10-inch diameter access holes were also made toward the bottom of each plenum for cleaning (Figure 2); the T-duct fan outlet was replaced with a 90° wide-sweep duct to reduce static pressure losses and because it was rusted through); and the weather cap was replaced with a vertical discharge outlet to reduce static pressure losses (Figure 3). Because the 90° duct had a wider radius than the T-duct, two 45° angle ducts were installed to align the exhaust with the existing mounting on the building. The stripping tank and plenums were thoroughly cleaned. There was no local exhaust ventilation system for control of methylene chloride emissions at the rinsing and drying areas during any of the three surveys.

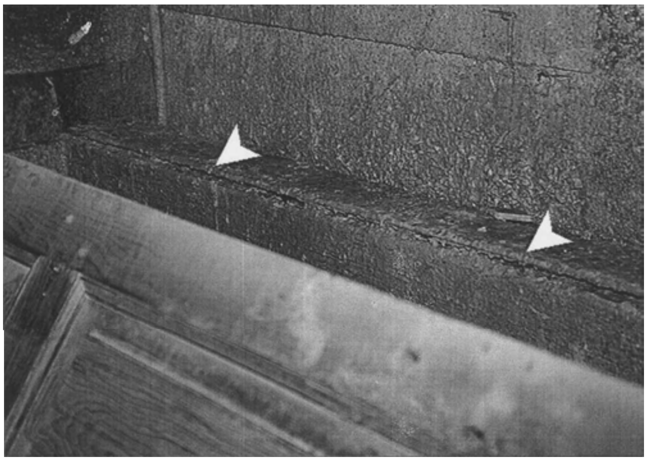

FIGURE 1
Clogged exhaust slots (shown at arrows) during the second survey.

FIGURE 2
Hole in front plenum showing debris in the plenum. Holes were covered to provide subsequent access.

DATA RESULTS AND ANALYSIS

Statistical analyses were conducted on the log-transformed data of the breathing zone, rinsing area, and stripping area sample results, after determining that these data could be described by a lognormal distribution. The first survey was analyzed

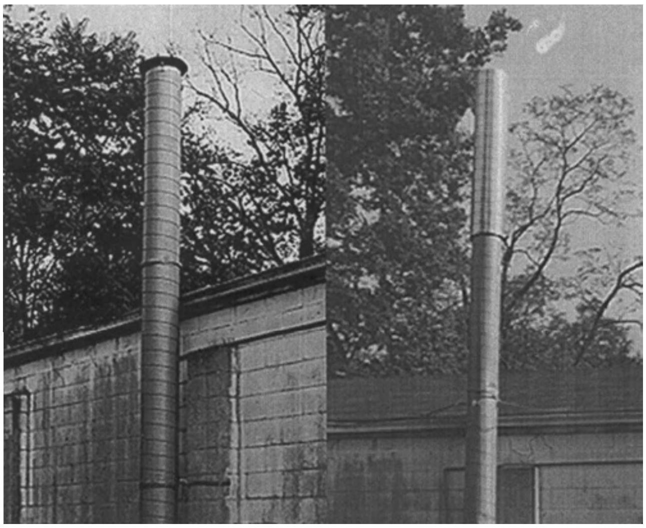

FIGURE 3
Left, weather cap used during second survey; Right, vertical discharge exhaust stack used during third survey.

FIGURE 4
Hinges (shown at arrows) added to the exhaust plenums for opening slots to aid in cleaning.

separately and only personal breathing zone data from one worker who was both stripping and rinsing was used for comparison to the second and third surveys. No new statistical analyses were conducted for the first study data. For the second and third surveys all samples were approximately one hour in length. Samples from the second and third surveys were studied in one statistical analysis (also with three other surveys that were reported in Estill et al.).[8] In the statistical model the variability of the runs by sample location (breathing zone, rinsing, or stripping) was treated as a random sample from a larger population. Our conclusions apply to the population of runs from which the selected runs were drawn. When both sampling methods were used simultaneously, the errors associated with these simultaneous determinations were correlated. This correlation was allowed for in the model.

Methylene chloride personal breathing zone and area sample results for the surveys are shown in Table I. Figure 5 shows the workers' exposures over the three surveys. Personal breathing zone results show a substantial increase from the first (59 ppm) to the second survey (332 ppm). Because of nonoverlapping 95 percent confidence intervals, the survey two breathing zone geometric mean exceeds the survey one breathing zone geometric mean at least with 90 percent confidence. A statistically significant reduction of 78 percent (CI 45%, 91%; $p = 0.0036$) was shown between the second and third (73 ppm) surveys. Exhaust volumes and air velocities show the opposite pattern (Table II). Exhaust volume decreased between the first (2900 cfm) and second (1060 cfm) surveys, followed by an increase during the third (2075 cfm) survey.

Bulk samples for the three surveys resulted in 69 percent methylene chloride by weight for the first survey and 49 percent for the third survey. No bulk samples were taken during the second survey.

During the second survey the amount of force to close the door was 4.7 lb. (s.d. = 0.7, for three attempts). This force is comparable to 0.05″ pressure.[3] This difference in fan static pressure is less than 10 percent of the difference between surveys two and three.

DISCUSSION

Maintenance to the ventilation system is an important function that may be overlooked by ventilation designers and subsequently by managers. The substantial increase in worker

TABLE I
Sampling results by survey

Survey	Sample location	Time each (min)	Number of samples	Methylene chloride concentration and 95% confidence levels (ppm) Geometric mean	Lower	Upper
1	Breathing zone[A]	120	10	59	56	63
2	Breathing zone	56	5	330	210	520
3	Breathing zone	60	8	73	31	180
1	Strip area	120	8	17	14	19
3	Strip area	60	8	9.8	4.1	23
1	Rinse area	120	12	24	21	29
2	Rinse area	56	5	59	38	92
3	Rinse area	60	8	23	9.6	55

[A]Survey one only used charcoal media. Other surveys used both charcoal and ORBO media.

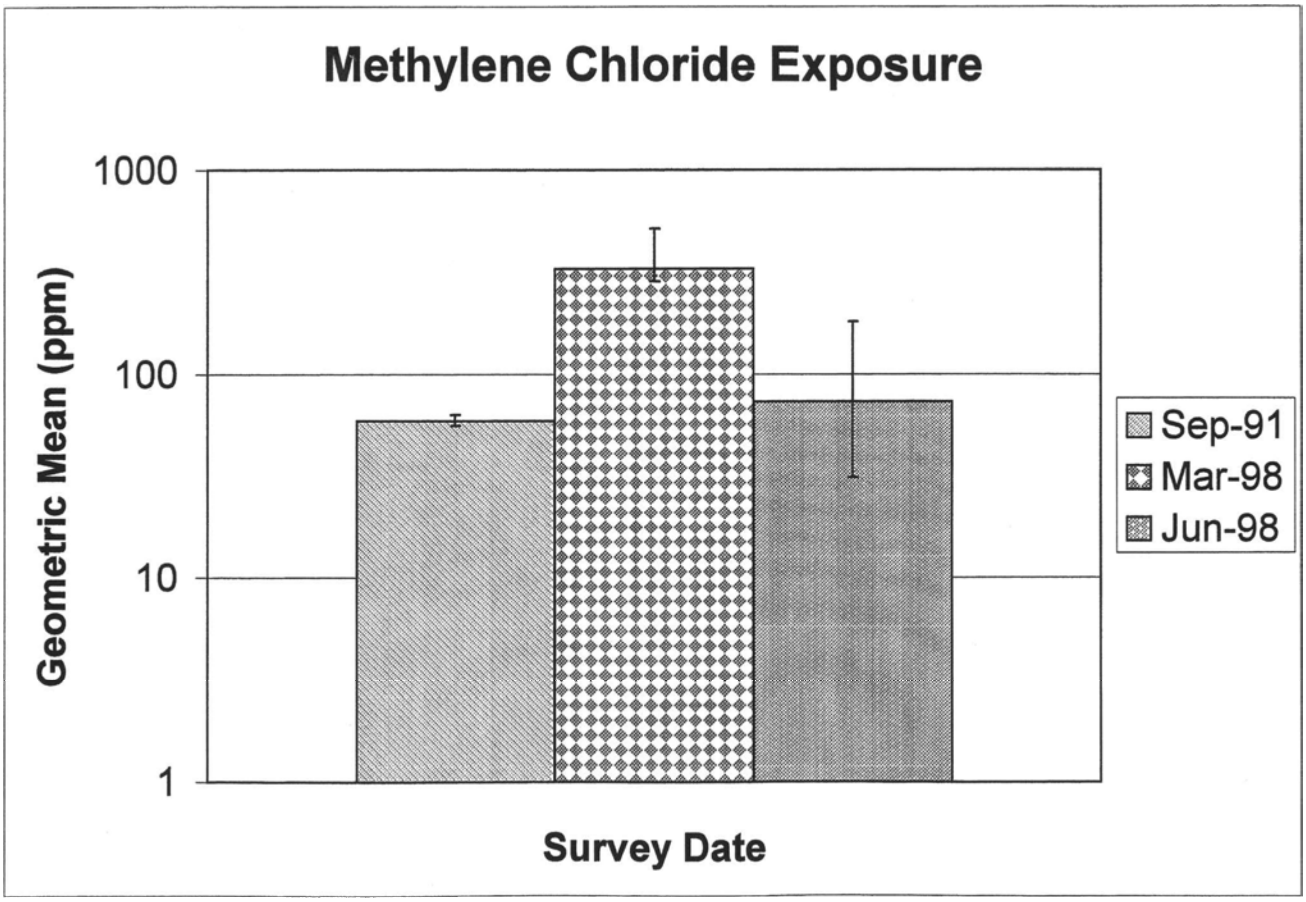

FIGURE 5
Graph of methylene chloride worker exposures during the three surveys.

exposures during the seven year interval between the first and second surveys can be at least partially attributed to the initial design of the ventilation system. The initial design did not include maintenance considerations. The configuration of the plenums did not allow access for the slots to be properly cleaned. Additionally, there was no way to remove the debris that had collected in the plenum. As a result of this design, the ventilation system progressively became less efficient. Much of the debris resembled the sawdust from sanding that had been performed in the building.

TABLE II
Ventilation measurements by survey

	Stripping tank		
Survey number	Exhaust volume (cfm)	Average slot velocity (fpm)	Static pressure[A] (WC)
1	2900	3200	[B]
2	1060	880	−0.52
3	2080	1700	−0.12

[A]Static pressure was measured near the duct outlet at eight duct diameters above the fan.
[B]Static pressure was not measured during the first survey.

The electrical capacity of the furniture stripping facility was also not considered in the initial ventilation design and led to the selection of a smaller fan than originally proposed. The smaller fan was not capable of pulling the same amount of air through the ventilation system that was achieved during the first survey. Besides electrical constraints, it was also found that natural gas usage at this facility was at a maximum and any additional need would require a larger gas line from the street. Ventilation designers need to be aware of electrical and gas utility limitations.

Apart from the problems mentioned above that can be attributed to the initial design, the ventilation system was not properly maintained. The fan and the ducts showed signs of deterioration (e.g., the bolts and housing on the fan were rusted, the belt was frayed and loose, and the T-duct was rusted through). Other researchers[1,4] have also found that business managers were likely to avoid preventive maintenance because of conflicting time demands.

The lack of make-up air was an additional factor that led partially to the increase in worker exposures. The doors and windows to the facility were closed during the second survey, allowing little means for outside air to enter the facility. This lack of make-up air caused at most 10 percent of the reduced efficiency between the second and third studies.

Other factors, which were not measured here, also affected workers exposures such as the height of the solution in the stripping tank and work practices. If the stripping solution is very low in the tank, the worker is forced to lean into the tank to reach the stripping solution. Alternatively, if the stripping solution is at a high level, the worker is able to stand erect and keep his face away from the exhaust intake. Work practices may also be important because of varying ways that solution-covered furniture is carried and because some workers rest their upper bodies on the tank side regardless of height of the solution.

Methylene chloride content of the furniture stripping solution is also an important factor. The stripping solution at this facility was mixed by the worker without a written recipe or documentation, leaving room for variation in the methylene chloride content of the stripper.

The operation of duct and fan systems can be graphically described by means of fan performance and duct system resistance curves. The fan performance curve describes the static pressure developed by the fan as a function of volumetric output. The duct system curve describes the resistance of the duct system as a function of the volumetric flow. For a simple duct system consisting solely of turbulent losses, the pressure loss varies as the square of the flow rate. The point of operation of the system curve is defined as the intersection of the fan and system curves.

Figure 6 illustrates the history of the fan and duct system installed at the furniture stripping facility. The first survey was conducted at the conditions indicated in Figure 6 (operating point 1). During this study a gasoline-powered fan was utilized as an air mover. The design flow rate was 2900 cfm at fan static pressure of 5.5″ WC. This fan was selected so that the point of operation would be located at a point on the fan performance curve with a steep negative slope, so that any misestimation of pressure loss would result in a relatively minor change in flow. The gasoline-powered fan was installed as a temporary measure, as the owner did not want to invest the needed capital for what was then a yet-to-be-proven benefit.

As was noted earlier, because of the unavailability of three-phase electrical power the facility owner selected the largest fan available with a single-phase motor. (Note: The fan was purchased from a catalog that contained fan performance data

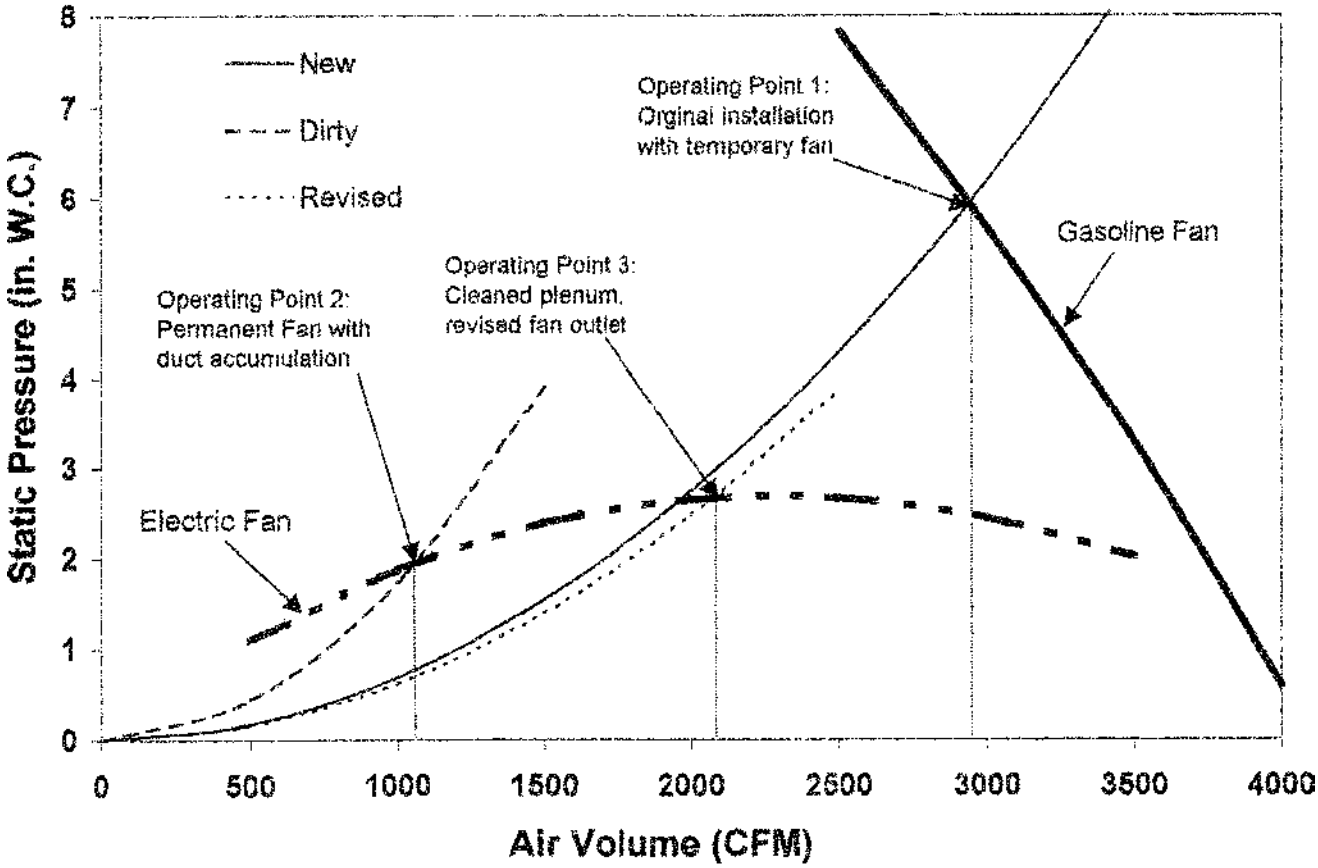

FIGURE 6
Fan and system changes.

but no fan curves.) Under ideal conditions, the fan selected would have exhausted approximately 1900 cfm from the stripping tank. Unfortunately, the operating point of this fan/duct system was located near the top of the fan performance curve. The result of this selection was a system that was extremely sensitive to increases in pressure. Measurements taken during the second study at this facility indicated that the system operating point had shifted due to the buildup of materials in the duct and plenum (operating point 2, Figure 6). For the third study, the modified fan outlet design, together with the duct cleanup made possible by the addition of the access ports, resulted in an increase in flow volume to 2100 cfm (operating point 3, Figure 6).

Figure 7 contains the system curve and fan performance curves for the 16 inch, 1890 rpm fan used during the second and third surveys, and a smaller, 14 inch, 2500 rpm fan, both utilizing 2 HP, single-phase motors. Figure 7 demonstrates that, had the smaller, higher speed fan been selected, the total flow would have been increased by about seven percent over the larger unit, and a more stable operation would have been achieved. The lesson learned: If no fan curves are available, plot your own—the smaller fan would have performed better at a lower first cost!

For newly installed ventilation systems, make sure that the new system meets the design specifications and controls the methylene chloride or other contaminants to below the legal requirements. Check the exhaust volume at eight duct diameters above the nearest disturbance (fan, elbow, taper, branch, etc.). Verify the fan rpm and HP and check the fan belt. Check the static pressure in each branch and in the main duct. The static pressure can be checked using a manometer or Magnehelic gauge by drilling (not punching) a hole in the duct at almost any location except at the heel of an elbow or similar location. If the new exhaust system meets design specifications, sample the worker's exposure to methylene chloride or other contaminants to determine if it is controlling exposures as expected.

A maintenance schedule should be provided to small business owners by ventilation designers or installers to help ensure that system performance is maintained. Based on the rate of accumulation of materials in the duct work observed, the following periodic maintenance schedule is recommended for furniture stripping shops to assure that ventilation systems operate as designed. Maintenance of ventilation systems should be performed according to manufacturer's recommendations; if those do not exist, use the recommendations provided here.

- Continually—Attach a Magnehelic gauge to a straight area of duct with a pressure tap that is soldered into the side. If the gauge is out of range then trouble shoot the system by verifying the fan curve, fan belt rpm, and slot velocity, and open to look for obstructions.

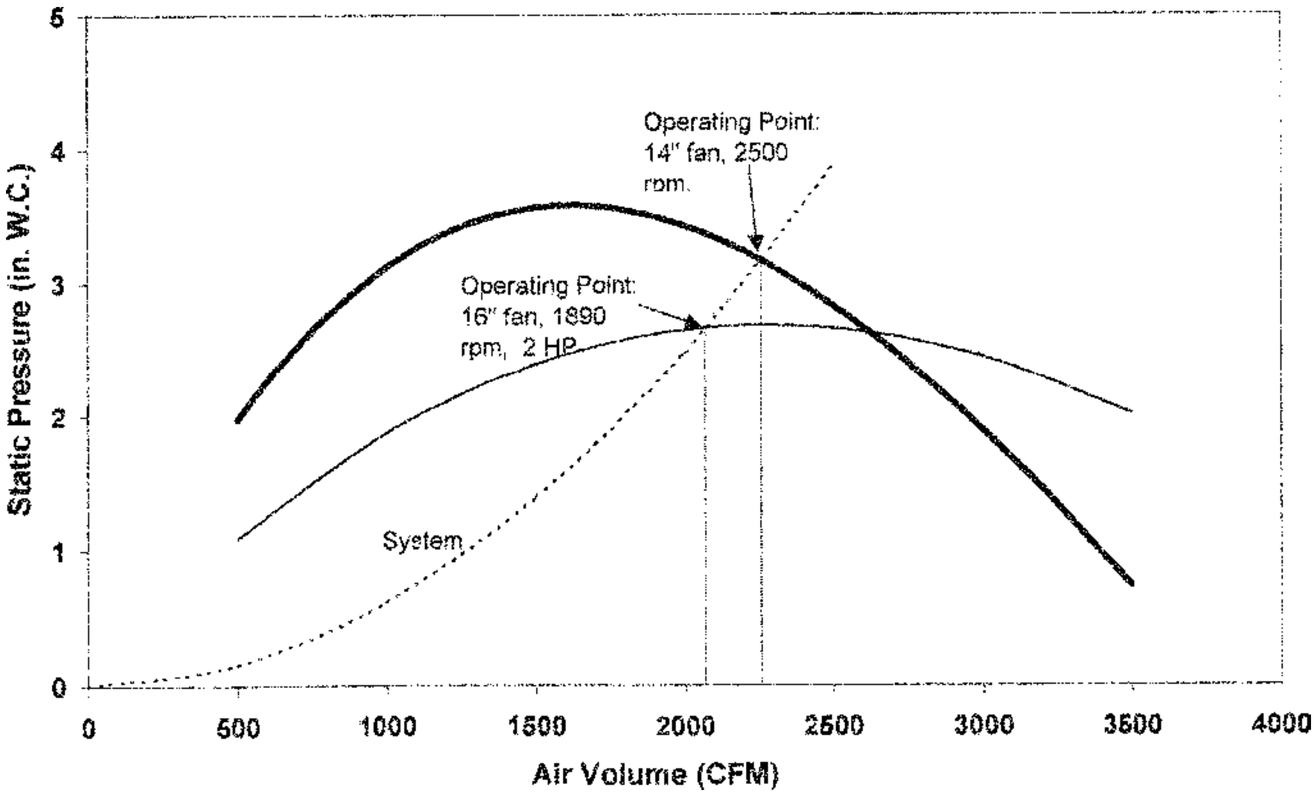

FIGURE 7
Enhanced performance with a smaller fan.

- Monthly—Open and clean the slots in the stripping tank. Open the fan only after properly de-energizing the fan's source of energy using current OSHA regulations.[15]
- Every six months—Open the access holes on the plenums of the stripping tank and clean out debris. Open the motor housing of the fan (after properly de-energizing) and check the belt to make sure that it is tight and not slipping and is not frayed or glazed. Grease the motor bearings and fan shaft.
- Yearly—Make sure that the blades are free from debris by opening the fan housing (after properly de-energizing) and wiping clean if necessary. Assure that the fan is free from rust and that connections between the inlet and exhaust ducts are intact.

CONCLUSIONS

The increase in exhaust volume and the reduction in worker exposure between the second and third surveys can be attributed to the cleaning and maintenance performed on the ventilation system. This maintenance and cleaning made the stripping area ventilation more effective. Although the exhaust volume will never be as high as that seen during the first survey because of the different fan, this volume was able to reduce methylene chloride exposures to a level comparable to the first survey. Additional controls (e.g., rinse area ventilation) were subsequently added to reduce the worker methylene chloride exposures in the shop to concentrations below the current OSHA PEL.[8]

This study showed that ventilation systems can severely deteriorate in a few years, which in turn can increase exposures. Cleanouts and other design characteristics that allow the ventilation system to be easily maintained should be provided on new and renovated ventilation systems. Additionally, managers should be made aware of preventive maintenance requirements.

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DISCLAIMER

Mention of company names and/or products does not constitute endorsement by the Centers for Disease Control and Prevention (CDC).

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