# IN-DEPTH SURVEY REPORT

# THE CONTROL OF METHYLENE CHLORIDE IN FURNITURE STRIPPING

at

Kwick Kleen Industrial Solvents, Inc
Vincennes, Indiana

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NATIONAL INSTITUTE FOR OCCUPATIONAL SAFETY AND HEALTH
Division of Physical Sciences and Engineering
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| | |
|---|---|
| FACILITY SURVEYED | Kwick Kleen Industrial Solvents, Inc<br>1202 Barnett Street<br>Vincennes, Indiana 47591-0905 |
| SIC CODE | 2851-Paints, Varnishes, Lacquers, Enamels, and Allied Products |
| SURVEY DATES | July 31 - August 2, 1989 |
| SURVEY CONDUCTED BY | Cheryl L Fairfield<br>Paul A Jensen, P E<br>James H Jones, C I H<br>Theodore F. Schoenborn |
| EMPLOYER REPRESENTATIVES CONTACTED | David White, Owner<br>Jay Bardole, Chemist |
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DISCLAIMER

# INTRODUCTION

The National Institute for Occupational Safety and Health (NIOSH) is the primary Federal organization engaged in occupational safety and health research  Located in the Department of Health and Human Services (DHHS), NIOSH was established by the Occupational Safety and Health Act of 1970  This legislation mandated NIOSH to conduct a number of research and education programs separate from the standard setting and enforcement functions carried out by the Occupational Safety and Health Administration (OSHA), which is located in the Department of Labor (DOL)  An important area of NIOSH research deals with methods for controlling occupational exposure to potential chemical and physical hazards  The Engineering Control Technology Branch (ECTB) of the Division of Physical Sciences and Engineering has been given the lead within NIOSH to study the engineering aspects of health hazard prevention and control

Since 1976, the Engineering Control Technology Branch has conducted a number of assessments of health hazard control technology on the basis of industry, common industrial process, or specific control techniques  The objective of each of these studies has been to document and evaluate effective control techniques for potential health hazards in the industry or process of interest, and to create a more general awareness of the need or availability of an effective system of hazard control measures

These studies involve a number of steps or phases  Initially, a series of walk-through surveys is conducted to select plants or processes with effective and potentially transferable control concepts or techniques  Next, in-depth surveys are conducted to determine both the control parameters and the effectiveness of these controls  The reports from these in-depth surveys are then used as a basis for preparing technical reports and journal articles on effective hazard control measures  Ultimately, the information from these research activities builds the data base of publicly available information on hazard control techniques for use by health professionals who are responsible for preventing occupational illness and injury

This study is part of a NIOSH initiative directed toward reducing the incidence of work-related diseases among workers employed by small businesses, particularly occupational lung disease, occupational cancer, occupationally related cardiovascular diseases, diseases due to neurotoxic agents, skin disease, hearing loss, and work-related injuries  Since many owners of small businesses lack basic knowledge regarding potential health effects and safe handling procedures, and at the same time are, for the most part, not subject to regular OSHA inspections, a concentrated effort on the part of NIOSH is necessary to implement these strategies in the small business sector  ECTB is in part responsible for developing recommendations for cost-effective engineering, administrative, and personal protective controls for small businesses

This particular research effort was prompted by the growing concern of the hazards of methylene chloride ($CH_2Cl_2$, Dichloromethane, or DCM) and the need for technical advice to furniture strippers  Furniture is stripped using a solution containing mostly methylene chloride and methanol  NIOSH has recommended that methylene chloride be considered a potential human carcinogen in the workplace [1] NIOSH further recommended that methylene chloride be controlled to the lowest feasible limit [2] Therefore, this study evaluates three local ventilation systems which use solution recycling-type furniture stripping tanks for worker's exposure to methylene chloride This study evaluates these local ventilation systems to general room ventilation and also compares temperature effects on the stripping solution This report will explain the stripping facility, ventilation systems, sampling techniques, results, and recommendations

FACILITY DESCRIPTION

Kwick Kleen Industrial Solvents, Inc produces, sells, and distributes furniture stripping solutions to over 2,000 furniture stripping shops Over 99% of the shops use one or more methylene chloride-based strippers Kwick Kleen estimates that they have between 10 to 15% of the stripping solution market Kwick Kleen has a furniture stripping room in their facility which is used for testing of stripping solutions and ventilation systems The stripping room contains a flow-over tank®, a rinse tank, a water purification tank, and a spray paint booth The floor plans of the stripping room are presented in Figure 1 There are doors at either end of the furniture stripping room There is a garage door at one end leading outside to part of the loading dock and there are double doors which lead to the warehouse and shipping area The stripping tank is located in one corner of the 15- by 40-foot room Adjacent to the stripping tank is the rinse tank and the water purification system

Kwick Kleen produces and sells many different kinds of furniture stripping solutions Their highest volume solution is No 125, which contains methylene chloride, methanol, and sodium hydroxide They produce other solutions in smaller quantities, which are special purpose strippers for a special type of wood or finish Besides the stripping solutions, they stock and distribute other products used by furniture strippers, such as gloves, brushes, tanks, aprons, finishes, etc Kwick Kleen also has a lab in which they test their solutions for quality control purposes, ability to work on the furniture finishes, and ability of the vapor retardant to form while using the chemical

PROCESS DESCRIPTION

Furniture stripping operations strip furniture to its original wood in order to put a new finish on the furniture Furniture to be stripped may come from institutions, businesses, or individuals The age of the furniture may vary from antique to modern The finish may also vary from paint coverings to stains or varnish Size may also vary from large cabinets to small stools Furniture must be stripped so that all the finish is carefully removed from every crack so that the wood is not damaged in any way Furniture stripping is a process which must be flexible to accommodate different sizes, types, and different finishes of furniture while still protecting the wood for its future finish

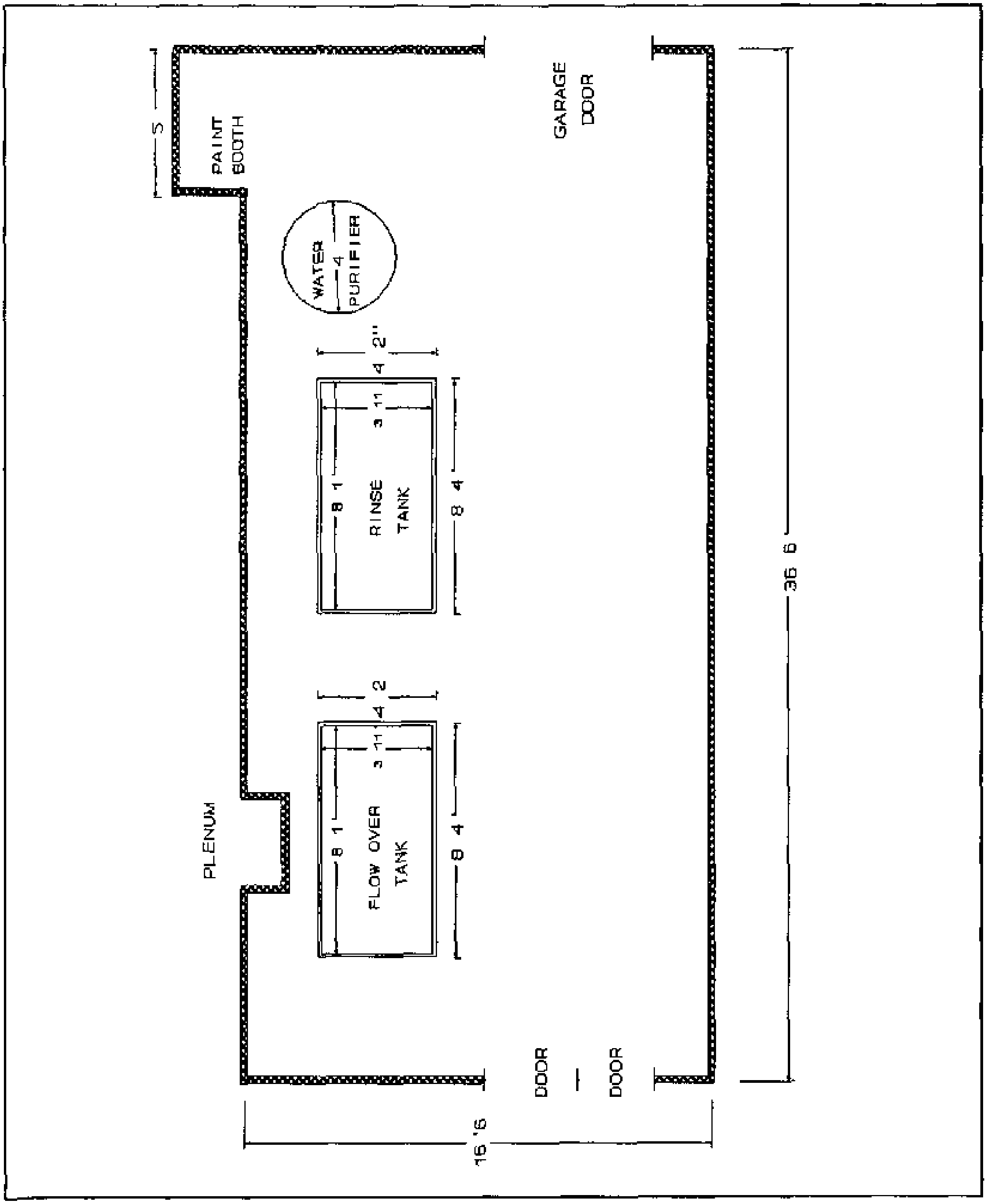


Figure 1 Stripping Room Layout

In response to the variability of furniture to be stripped, this facility uses a large, open tank called a flow-over tank®, which was designed, marketed, and patented by Kwick Kleen The stripping process is relatively simple cover the furniture with stripping solution, let the solution work on the finish, brush over the piece, rinse the solution off the piece, and set it aside

The tank is made of galvanized steel and is 4 by 8 feet The lip of the tank stands 3 feet from the floor, with depth in the tank ranging from 9 inches to 13 inches The bottom of the tank is sloped with a drain at the low end Along with the open tank, there is a solution recycling system The system includes a 5-gallon pail, a pump, and a brush with plastic tubing connecting the three The pail is located under the drain in order to catch the used solution Solution is pumped from the pail out through the brush and into the tank, which returns the solution back to the pail through the drain

Kwick Kleen No 125 was the solution used at this facility The stripping solution is made of methylene chloride, methanol, and sodium hydroxide There is also wax or paraffin in the solution which acts as a vapor barrier The solution was made so that when the solution is covering a piece of furniture, the wax forms an outer barrier in order to prevent excessive evaporation of the chemical Kwick Kleen, who manufacturers this solution, recommends the solution's temperature be between 70 and 85 °F When used in this temperature range, the wax is allowed to form a vapor barrier on the surface of the liquid while some wax is suspended in the stripping solution

When actually stripping, furniture is placed into the tank and covered with the solution The solution begins to work on the furniture When the solution is working, the finish begins to blister The piece is brushed, turned, and recovered with solution as needed Once the finish is removed from the piece, the stripping solution must be rinsed off

The rinse tank at this facility is made of galvanized steel, it is an open tank with two side panels which enclose one side and one end The tank is made to capture the run-off water below the area that the piece is rinsed There is a platform which is 2 feet from the floor where the piece is rinsed The platform has openings on the sides for the water to collect below The water is sprayed in the direction of the side panels, so that all water is captured

Once the piece is rinsed, it is sprayed with an aqueous oxalic acid solution while still on the rinse tank The acid is sprayed on the furniture after stripping to lighten the wood to its original color

Finally, the piece is set aside to dry Once dry, the piece will be sanded and finished

The hood ventilation system consisted of three enclosed sides (back, right, and left) with a slot which opened upward at the base of each side (see Figures 2 and 3) Air is exhausted from the tank work area through the upward facing slot which is located at the edge of the tank on three sides These slots were to capture the air at the tank level On the sides of the hood were baffles to cut down on cross drafts and to get fresh air to come in

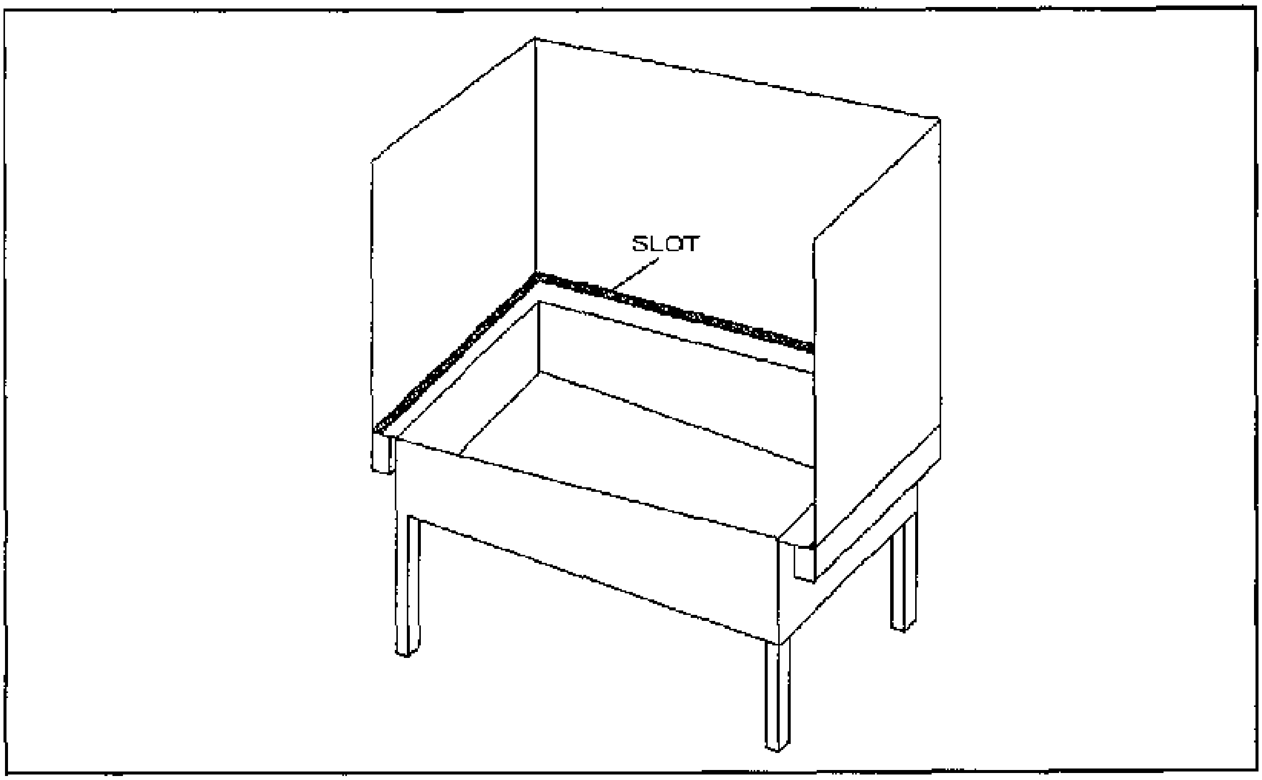


Figure 2 Hood Ventilation System

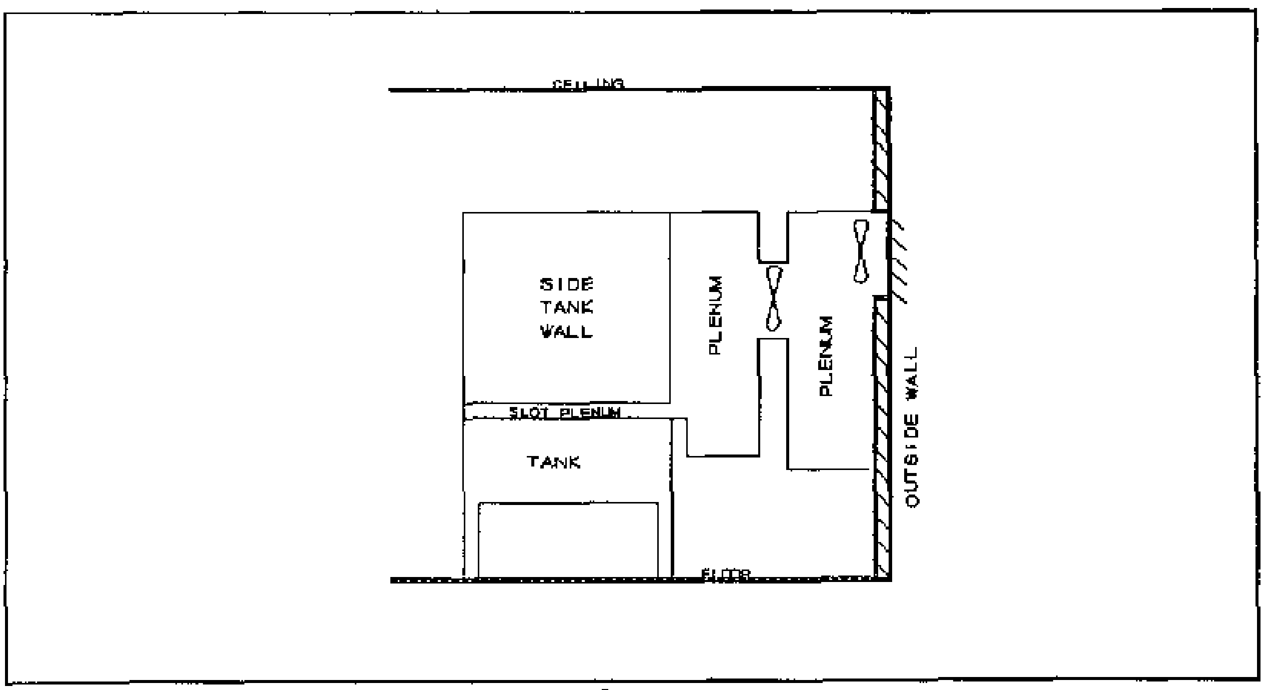


Figure 3 Side View of Hood Ventilation System

through the front of the tank There were two fans connected to this system in series

The PVC pipe ventilation system consisted of two PVC pipes with openings facing downward at the front right and back right corners of the tank (see Figures 4 and 5) The PVC pipe was 6 inches in diameter From the edge of the tank, the pipes made a 90 degree turn to horizontal, then came together perpendicularly into one pipe of the same diameter and went down to the floor and into the bottom of a rectangular plenum The plenum is on the wall and is 2 feet wide and 10 inches deep and goes from about 2 feet off the floor to 6 feet from the floor There is a fan exhausting from this plenum to the outside

The floor ventilation system (Setup 3) consisted of a plenum on the wall behind the flow-over® tank with the opening of the plenum facing downward about 2 feet from the floor (see Figures 6 and 7) The tank was pushed against the plenum which was about 2 feet wide by 10 inches deep The plenum went up to 6 feet from the floor, where there was a fan which exhausted to the outside This system exhausted the air which is at the floor level Whereas, the first two systems exhaust air at the source

POTENTIAL HAZARDS

Potential chemical hazards in the furniture stripping industry are found whenever an individual is in contact with the stripping solution, which contains a mixture of methylene chloride, methanol, and sodium hydroxide (70, 25, and 1% by volume, respectively) [3] Exposures are found during the actual

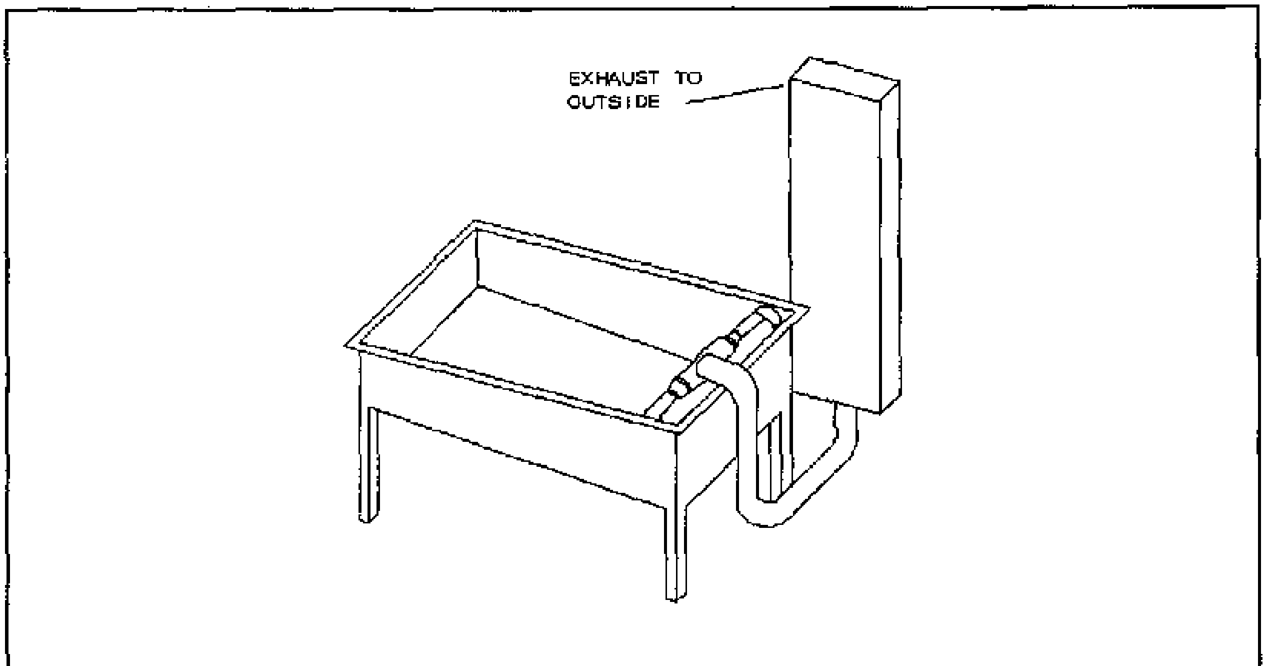


Figure 4 PVC Pipe Ventilation System

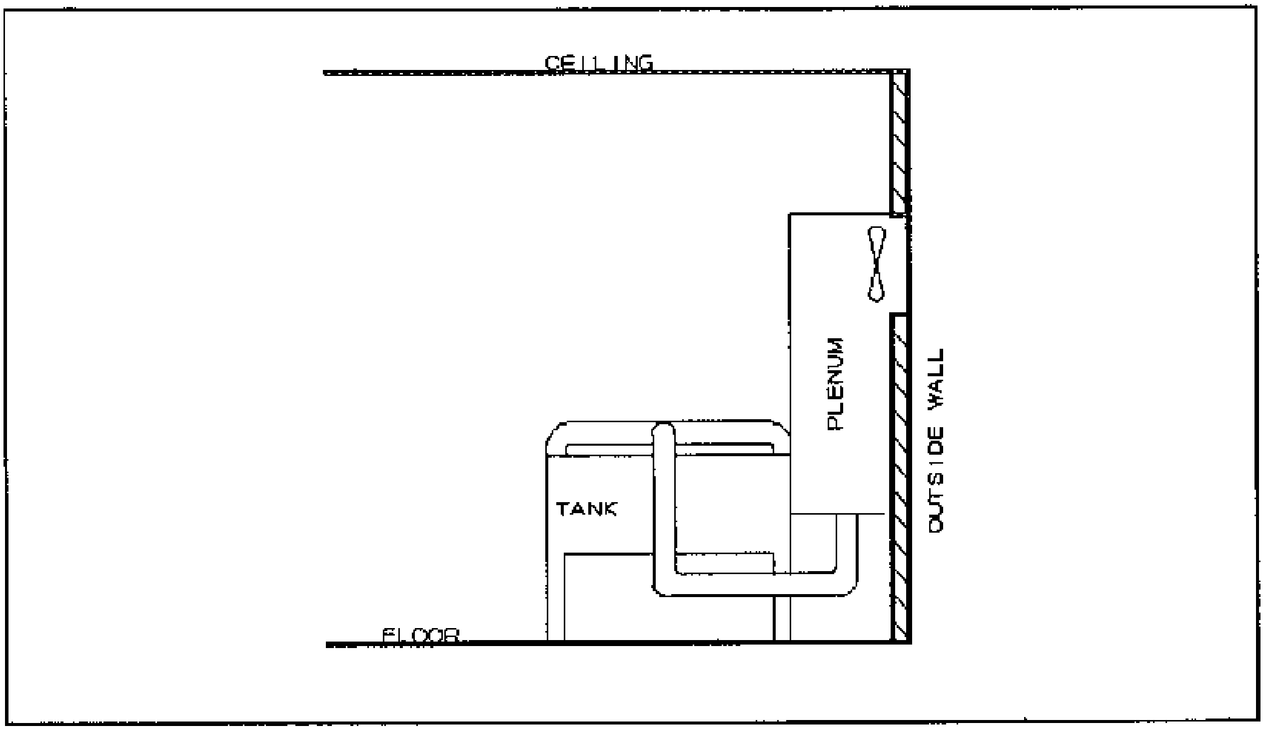


Figure 5        Side View of PVC Pipe Ventilation System

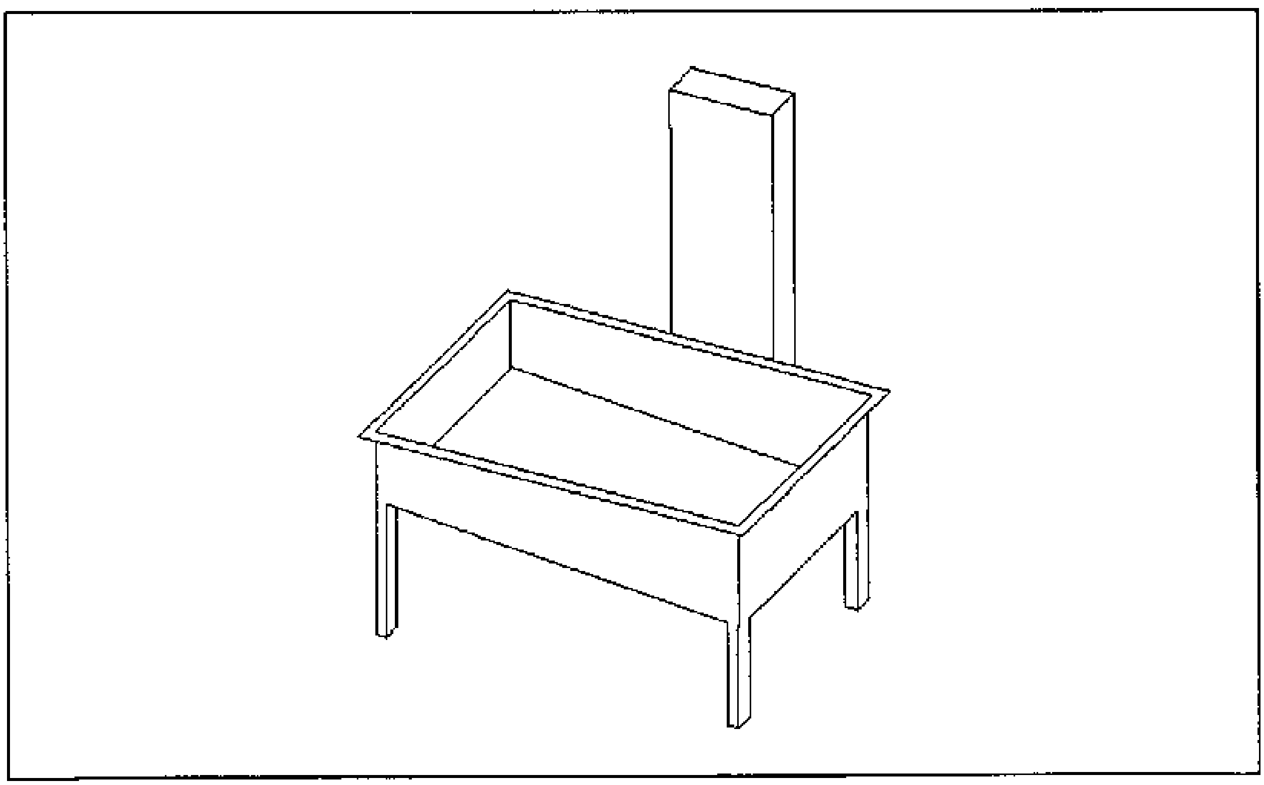

Figure 6        Floor Ventilation System

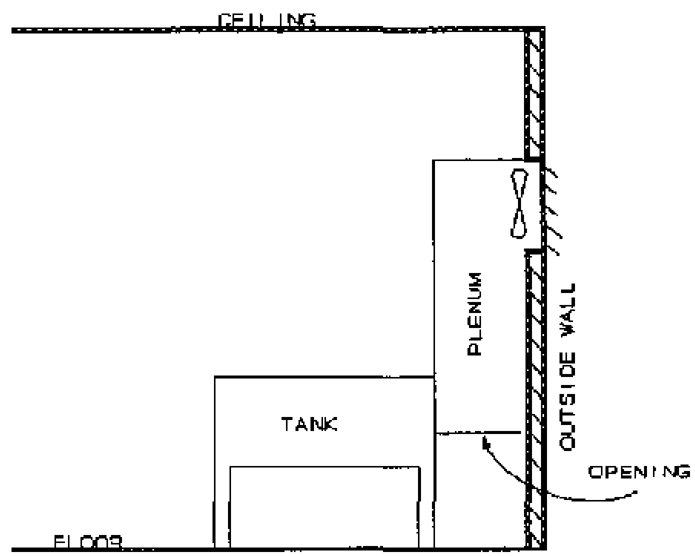


Figure 7        Side View of Floor Ventilation System

stripping, rinsing, or moving of furniture, as well as when transferring stripping solutions from the evaporation of the solution  The major routes of entry of methylene chloride and other solvents into one's body include inhalation of vapors into the lungs and absorption of the liquid through the skin

Methylene chloride was once reported to be the least toxic of the chlorinated methanes  Health effect studies have been focused on three primary areas effects on the central nervous system, effects on cardiovascular morbidity and mortality, and induction of cancer in exposed workers  More recent research has shown methylene chloride to be a possible reproductive toxicant  In addition, solvents are known to affect liver function, and some studies address whether this effect occurs secondary to methylene chloride exposure

Central Nervous System Effects

The short-term health effect of methylene chloride most frequently cited in the literature is a depressant effect on the central nervous system  Exposure results in narcosis, and symptoms of lightheadedness, lethargy, and disequilibrium  These symptoms are similar to those seen with other organic solvents

The first reports of the effects of methylene chloride on the neurologic function of humans were from its use in the 1920's as an anesthetic  Recent studies have looked at the effects of short-term methylene chloride exposure on neuropsychological function Levels of exposure as low as 200 ppm of methylene chloride caused diminished performance in an eye-hand coordination exercise, and in an auditory vigilance test [4]

There is not extensive data on the central nervous system effects of methylene chloride It is reasonable to assume that it can cause the same degree of neurotoxicity demonstrated from exposure to other chlorinated solvents and to carbon monoxide, and can potentially cause chronic irreversible brain damage [5]

Cardiovascular Effects

Methylene chloride is metabolized in the body to carbon monoxide and carbon dioxide It is reasonable to suspect that the cardiovascular health effects known to occur from carbon monoxide exposure may occur with methylene chloride exposure as well Carbon monoxide binds to the hemoglobin of red blood cells, and prevents the binding of oxygen The capacity of the cardiovascular system to carry oxygen to the tissues depends on this binding, so carbon monoxide exposure can lead to death from lack of oxygen This can also precipitate a heart attack in a susceptible individual The exposure to carbon monoxide can be determined by measuring the carboxyhemoglobin during or shortly after cessation of exposure

Increased carboxyhemoglobin levels have been associated with a decrease in maximum exercise capacity and oxygen utilization [6] Men, who were known to have underlying coronary artery disease and exposure to carbon monoxide, experienced a shorter time between exercise and the onset of cardiac-induced chest pain [7]

There have been two epidemiologic studies, which specifically investigated the cardiovascular mortality and morbidity of populations exposed to methylene chloride The first examined the proportional mortality ratios of personnel at Eastman Kodak [8] The authors found that the population exposed to methylene chloride had a lower overall mortality, and lower cardiovascular mortality than the New York state population, in addition they found no difference in death rates between the exposed and an unexposed Kodak group This study was limited by the fact that there were only a total of 45 deaths in the group of workers, with over 20 years since their first exposure to methylene chloride In addition, all workers who ever worked with methylene chloride were included, leading to the possibility that significant dilution of any effect may have resulted

The second study was of Dow Chemical employees, some of whom were exposed to methylene chloride in a fiber production plant which used methylene chloride and acetone as solvents, the unexposed cohort group worked in a similar facility and used acetone alone [9] Two Dow exposure groups existed, in one, workers were exposed to an 8-hour time-weighted average of 140 ppm methylene chloride, and in the other, to 475 ppm Based on a review of death records, the authors concluded that there was no evidence of increased cardiovascular mortality or morbidity, but another author stated that there is some very suggestive evidence in the paper that leads to the opposite conclusion For instance, there were only 50 total deaths in the cohort mortality study, and only 14 cardiovascular deaths The exposed group had an elevated relative risk for cardiovascular death when compared to the nonexposed population, and both had lower cardiovascular mortality, but a more conservative interpretation would be that it suggests an increased risk from methylene chloride exposure [10] A subset of the study looked at carboxyhemoglobin levels in exposed workers The carboxyhemoglobin levels taken before work increased as the week progressed, demonstrating that the clearance time for the carbon monoxide secondary to methylene chloride metabolism is greater than 24 hours

Carcinogenicity

The National Toxicology Program (NTP) inhalation bioassay of methylene chloride was conducted on F344/N rats and B6C3F1 mice The exposure concentrations used were 0, 1,000, 2,000, or 4,000 ppm for rats and 0, 2,000, or 4,000 ppm for mice, for a period of 2 years The reviewers concluded that under the conditions of the inhalation studies, there was "some evidence of carcinogenicity" of methylene chloride for male rats as shown by an increased incidence of benign neoplasms of the mammary gland There was "clear evidence of carcinogenicity" of methylene chloride for female rats as shown by an increased incidence of benign neoplasms of the mammary gland There was "clear evidence of carcinogenicity" of methylene chloride for male and female mice as shown by an increased incidence of alveolar/bronchiolar neoplasms and hepatocellular neoplasms [11]

The U S Environmental Protection Agency (EPA) has classified methylene chloride as a Probable Human Carcinogen (Group B2) The EPA Probable Human Carcinogen classification (Group B) is used when there is sufficient evidence of carcinogenicity in animals and evidence of carcinogenicity from epidemiological studies that ranges from "almost sufficient to inadequate " The category is divided into higher (Group B1) and lower (Group B2) degrees of evidence The B1 category is reserved for those agents for which there is at least some limited evidence of carcinogenicity to humans from epidemiological studies In the absence of adequate data in humans, it is reasonable to regard agents for which there is sufficient evidence of carcinogenicity in animals as probable carcinogens in humans Agents for which there is sufficient evidence from animal studies but insufficient evidence from human studies are classified as B2 [12,13]

Reproductive Toxicant

The NTP study also noted increased incidences of testicular atrophy in male rodents, and ovarian and uterine atrophy in female rodents exposed to methylene chloride The report stated that these changes may have been secondary to the extensive lung and liver neoplasia produced by the inhalation exposure

Locally, the Greater Cincinnati Occupational Health Clinic reported four cases of workers who had exposure to methylene chloride and who had both excessive serum levels of carboxyhemoglobin and low sperm counts [14] As a result of this finding, NIOSH conducted a small field study to confirm these results, however, a much larger cohort is needed to statistically validate the finding of methylene chloride as a reproductive toxicant [15]

ENVIRONMENTAL CRITERIA

As a guide to the evaluation of the hazards resulting in workplace exposures, NIOSH field staff employ environmental evaluation criteria for assessment of a number of chemical and physical agents These criteria are intended to suggest levels of exposure to which most workers may be exposed up to 10 hours per day, 40 hours per week, for a working lifetime without experiencing adverse health effects It is, however, important to note that not all workers will be protected from adverse health effects if their exposures are maintained below these levels A small percentage may experience adverse health effects because of individual susceptibility, a preexisting medical condition, and/or a hypersensitivity (allergy) In addition, some hazardous substances may act in combination with other workplace exposures, the general environment, or with medication or personal habits of the worker to produce adverse health effects even if the occupational exposures are controlled at the level set by the evaluation criterion These combined effects are often not considered in the evaluation criteria Also, some substances are absorbed by direct contact with the skin and mucous membranes, and thus potentially increase the overall exposure Finally, evaluation criteria may change over the years as new information on the toxic effects of an agent become available

The primary sources of environmental evaluation criteria for the workplace are (1) NIOSH recommended exposure limits (RELs), (2) the American Conference of Governmental Industrial Hygienists (ACGIH) Threshold Limit Values (TLVs®), and (3) the U S Department of Labor (OSHA) permissible exposure limits (PELs) Often, the NIOSH RELs and ACGIH TLVs are lower than the corresponding OSHA PELs Both NIOSH RELs and ACGIH TLVs usually are based on more recent information than are the OSHA PELs The OSHA PELs are required to take into account the feasibility of controlling exposures in various industries where the agents are used, the NIOSH RELs, by contrast, are based primarily on concerns relating to the prevention of occupational disease In evaluating the exposure levels and the recommendations for reducing these levels found in this report, it should be noted that industry is legally required to meet only those levels specified by the OSHA PELs

A time-weighted average (TWA) exposure refers to the average airborne concentration of a substance during a normal 8- to 10- hour workday Some substances have recommended short-term exposure limits or ceiling values which are intended to supplement the TWA where there are recognized toxic effects from high short-term exposures In 1986, NIOSH recommended that methylene chloride be regarded as a "potential occupational carcinogen " NIOSH further recommended that occupational exposure to methylene chloride be controlled to the lowest feasible limit This recommendation was based on the observation of cancers and tumors in both rats and mice exposed to methylene chloride in air [1]

Previously, the NIOSH REL for methylene chloride was 75 ppm, as a TWA for up to 10 hours per day, 40 hours per week, with a 500 ppm peak exposure as determined over any 15-minute sampling period during the workday. This REL was based on the need to prevent significant reduction in the oxygen carrying capacity of the blood which affects the central nervous system.[16]

The current OSHA PEL for methylene chloride is an 8-hour TWA concentration of 500 parts per million (ppm), with a ceiling concentration of 1,000 ppm, and maximum peak concentration of 2,000 ppm for no more than 5 minutes within any 2 hours. This PEL was derived from a standard recommended by the American Standards Institute (ANSI) and adopted in 1971 without rulemaking.[2] In 1986, OSHA published an Advanced Notice of Proposed Rulemaking. OSHA is considering revising the present occupational health standard because of scientific studies which have reported that inhalation of methylene chloride has caused cancer in two animal species.[17]

The 8-hour TLV established by the ACGIH is 50 ppm and ACGIH has classified methylene chloride as a suspected human carcinogen. This TLV was lowered from 100 ppm in order to provide a wider margin of safety in preventing liver injury. This level is recommended in the absence of occupational exposure to carbon monoxide. The old TLV of 100 ppm is based on experimental data obtained from male, nonsmoking subjects at rest. The ACGIH stated that the blood of workers who were exposed at 100 ppm of methylene chloride would have carboxyhemoglobin levels below 5% in their blood. Normal carboxyhemoglobin saturation ranges from 0.4 to 0.7% for nonsmokers and 4 to 20% for smokers. The ACGIH further cautioned that "concurrent exposures to other sources of carbon monoxide or physical activity will require assessment of the overall exposure and adjustment for the combined effect."[18]

The NIOSH REL for methanol is 200 ppm, as a TWA for up to 10 hours per day, 40 hours per week, with a ceiling of 800 ppm averaged over a 15-minute period. The current OSHA PEL for methanol (29 CFR 1910.1000 Table Z-1-A) is an 8-hour TWA concentration of 200 ppm.[2] The 8-hour TWA-TLV established by ACGIH is 200 ppm, with a 250 ppm STEL.[18]

## STUDY METHODS

The objective of this study was to evaluate the local ventilation systems designed by Kwick Kleen Industrial Solvents, Inc. for their ability to minimize the amount of methylene chloride in which a worker is exposed. Three local ventilation systems were used in conjunction with a flow-over® furniture stripping tank: a hood ventilation system, a PVC pipe ventilation system, and a floor ventilation system. The hood and PVC pipe ventilation systems were prototypes set up for this study. The floor ventilation system is the system that Kwick Kleen normally uses and recommends to furniture stripping shops.[19] The study strategy consisted of five different sampling setups or configurations. During the setups, the ventilation system and temperature of the solution varied in order to determine if there was an exposure difference between setups when ventilation systems and stripping solution temperature are varied. The temperature of the solution was normally kept at about 70 °F, during the fifth setup, the temperature was lowered using ice. One of the three ventilation systems were used during each setup except Setup 4, this setup consisted of just general ventilation. Table A shows the study strategy.

| Table A Sampling Strategy | | | | |
|---|---|---|---|---|
| Date | Setup | Ventilation System | Average Solution Temperature °F | Number of Chairs |
| 7/31 | 1 | Hood | 70 | 9 |
| 8/01 | 2 | PVC Pipe | 70 | 9 |
| 8/01 | 3 | Floor | 70 | 9 |
| 8/02 | 4 | Control | 70 | 6 |
| 8/02 | 5 | Floor | 63 | 6 |

We compared the temperature of the stripping solution during Setup 3 to Setup 5 During Setup 5, the solution pail was placed in a container with ice The temperature during the third setup remained almost at a constant 70 °F The temperature during the fifth setup was at 70 °F for the first run and then was finally lowered to 56 °F during the second run Figures 8 and 9 show the change in temperature of the stripping solution over time for the third and fifth setups, respectively

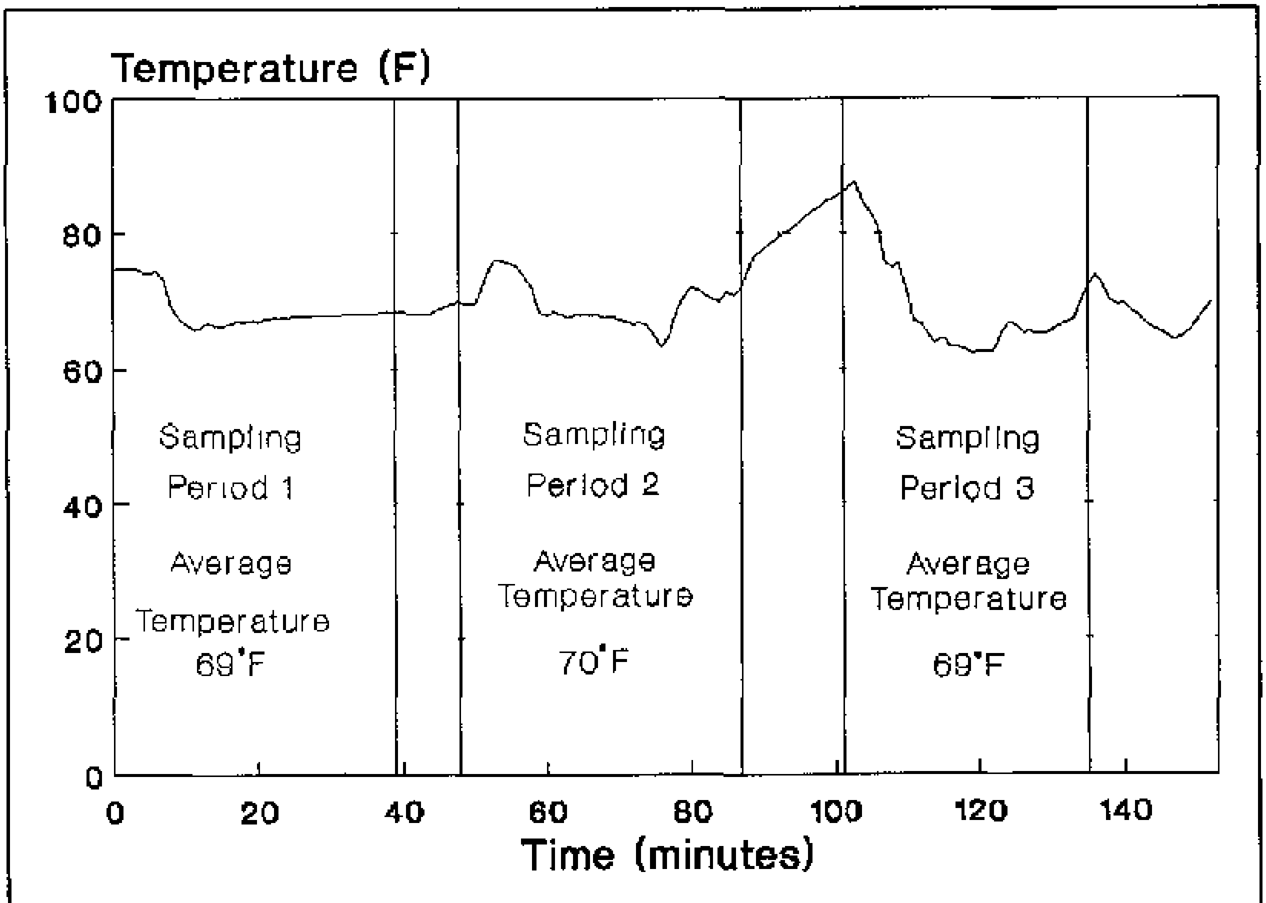


Figure 8 Solution Temperature During Stripping – Setup 3

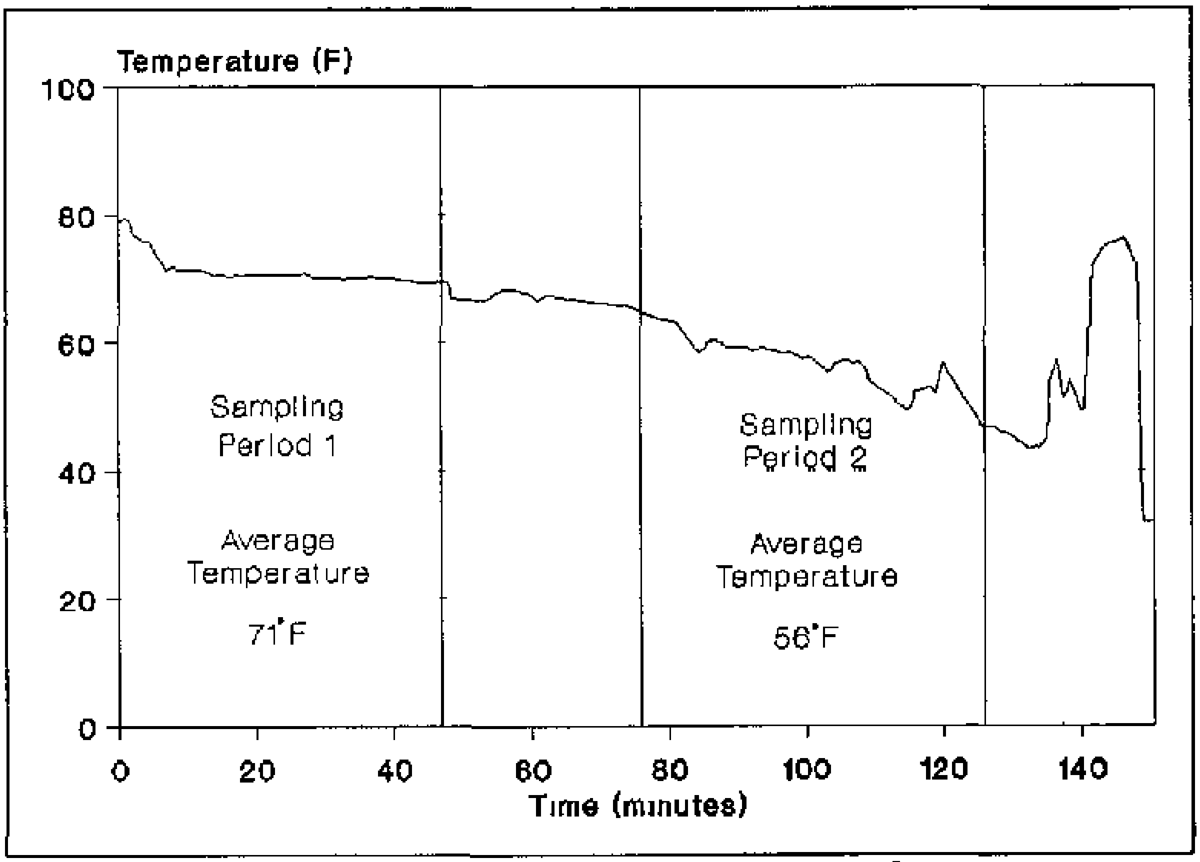


Figure 9 Solution Temperature During Stripping - Setup 5

Kwick Kleen was able to strip a large quantity of similar chairs for this study All chairs were made of the same wood, design, and finish Therefore, the chairs required a similar amount of solution and time to remove their finish Personal air samples for methylene chloride and methanol were collected side by side in the breathing zone of the worker for each setup Also, a number of area samples for methylene chloride and methanol were taken at the back wall of the stripping room, the floor level, the flow-over® tank, and the rinse tank For locations of area samples, see Figure 10 All sorbent tubes were sent to DataChem (Salt Lake City, Utah) for analysis using NIOSH Method 1005 for Methylene Chloride and NIOSH Method 2000 for Methanol Ventilation measurements were assessed using a Kurz Digital Air Velocity Meter Model 1440-4 (Kurz Instruments, Inc , Monterey, California) to find the velocity of the air at the face of the tank

Sampling for methylene chloride was collected on two 50/100 mg charcoal coconut sorbent sample tubes (SKC 226-01, SKC, Inc , Eighty-four, Pennsylvania) in series Samples for methanol were collected on one 75/150 mg silica gel sorbent tube (SKC 226-10, SKC, Inc , Eighty-four, Pennsylvania) Sampling for both methylene chloride and methanol was administered at a flow rate of 0 02 liters per minute (lpm) using a personal sampling pump (P200A, E I DuPont deNemours and Co , Inc , Wilmington, Delaware) Temperature of stripping solution was measured with a Bailey Digital Thermometer (BAT-8, Bailey Instruments, Inc , Saddle Brook, New Jersey) The signal was collected

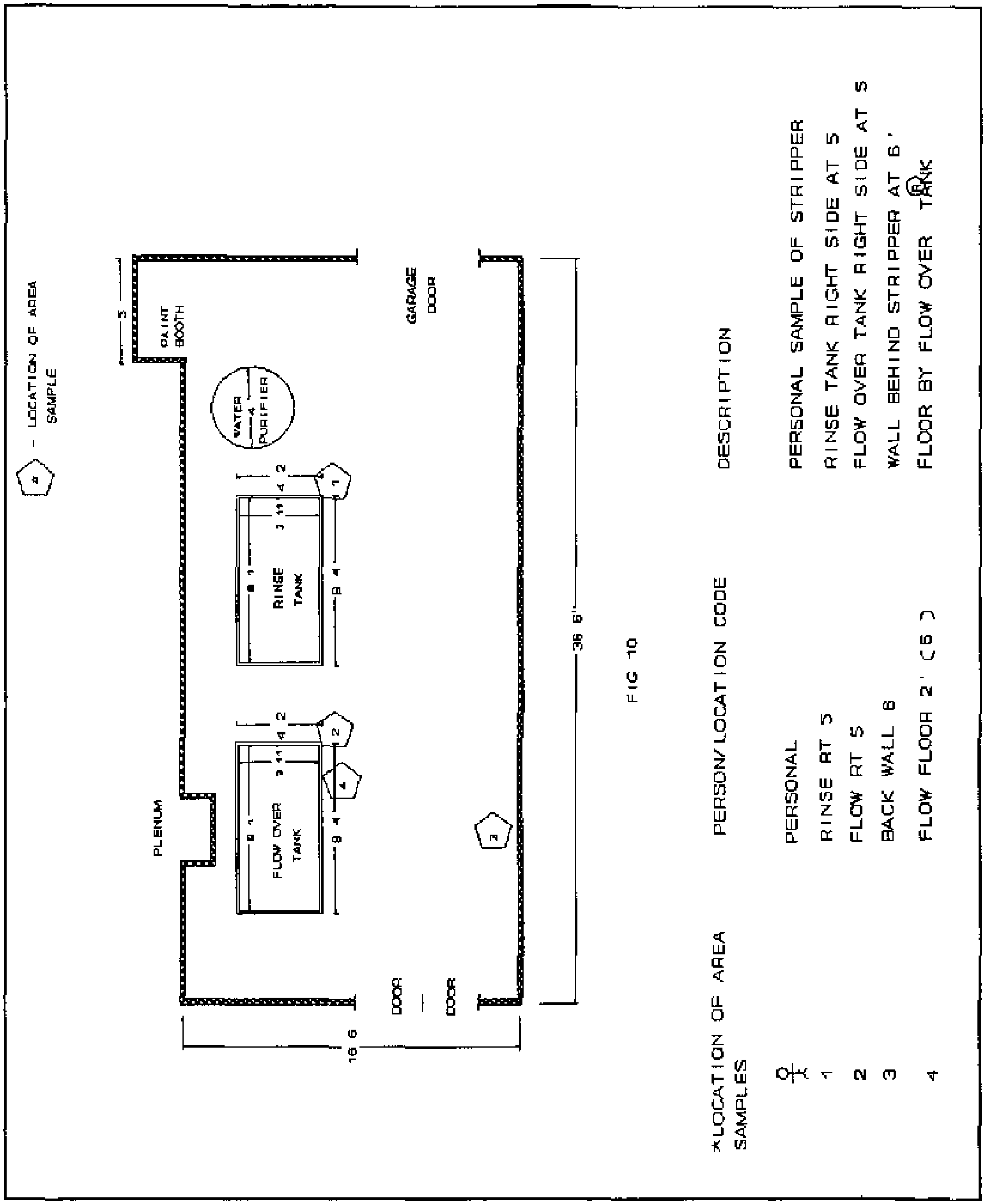


Figure 10 Location of Area Samples

on a Rustrak® Ranger data logger (Gulton Industries, Inc , E Greenwich, Rhode Island)

SAMPLING MEASUREMENTS

Figure 11 shows the personal exposures to methylene chloride during each sampling period This is the graph of most concern, because these concentrations relate directly to the amount of methylene chloride the worker is exposed to using this control Setups 1, 2, and 3, which used local ventilation at the recommended stripping solution temperature, all averaged close to 200 ppm Setup 4, the control, had an average personal exposure of close to 600 ppm, while Setup 5, which used the cooled stripping solution with a floor ventilation system, had an average personal exposure of 373 ppm

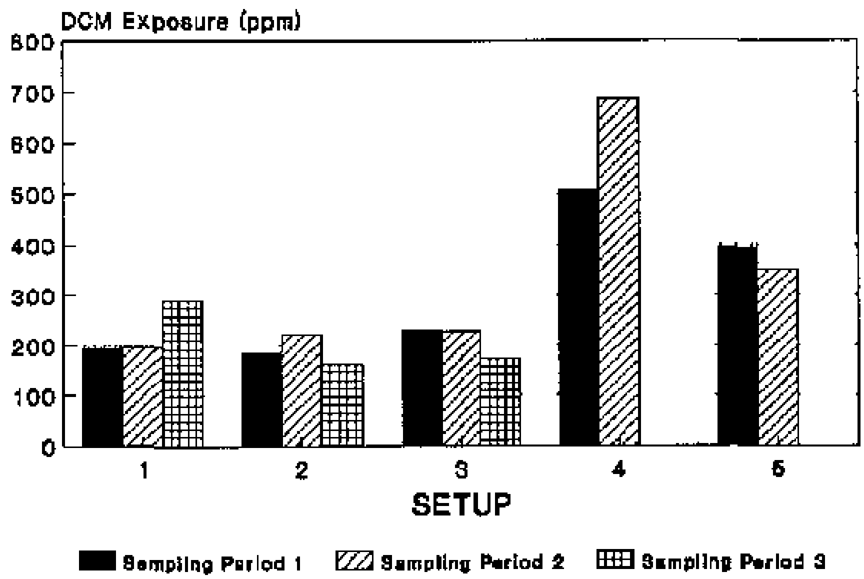


Figure 11 Personal Exposure to Methylene Chloride

Area samples were taken at the flow tank, the rinse tank, near the floor, and at the back wall Figures 12, 13, 14, and 15 show the concentrations in parts per million (ppm) of methylene chloride for those areas during each sampling period

The graph, Figure 16, titled "concentration at different heights" refers to methylene chloride concentration during Setup 4 This graph shows that for these concentrations the highest concentration of methylene chloride is located close to the floor However, even at 6 feet high, the concentration was still close to 500 ppm The second sampling period appears to be higher for all heights because without the ventilation the room concentration seemed to be increasing Methanol samples were taken in the breathing zone of the worker to show personal exposures to methanol during furniture stripping Methanol exposures during the Setups 1, 2, and 3 using the local

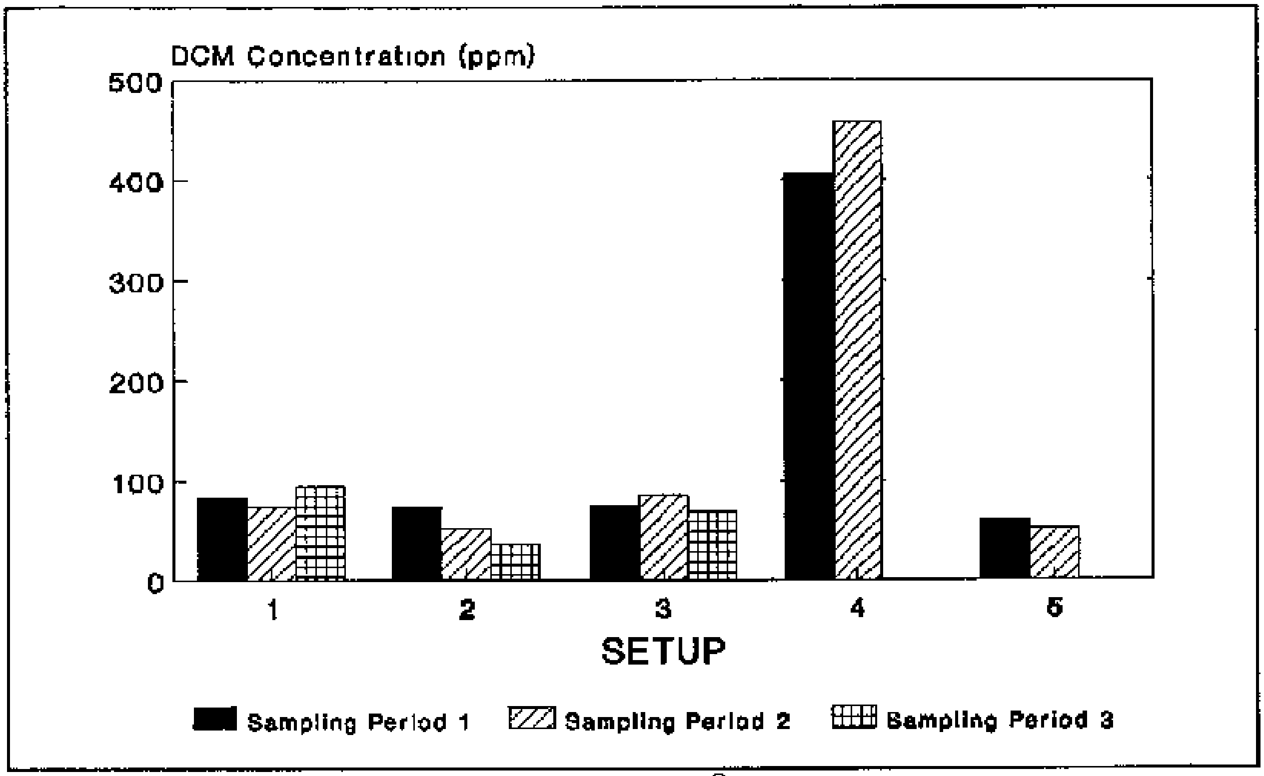


Figure 12 DCM Concentration at Flow-Over® Tank

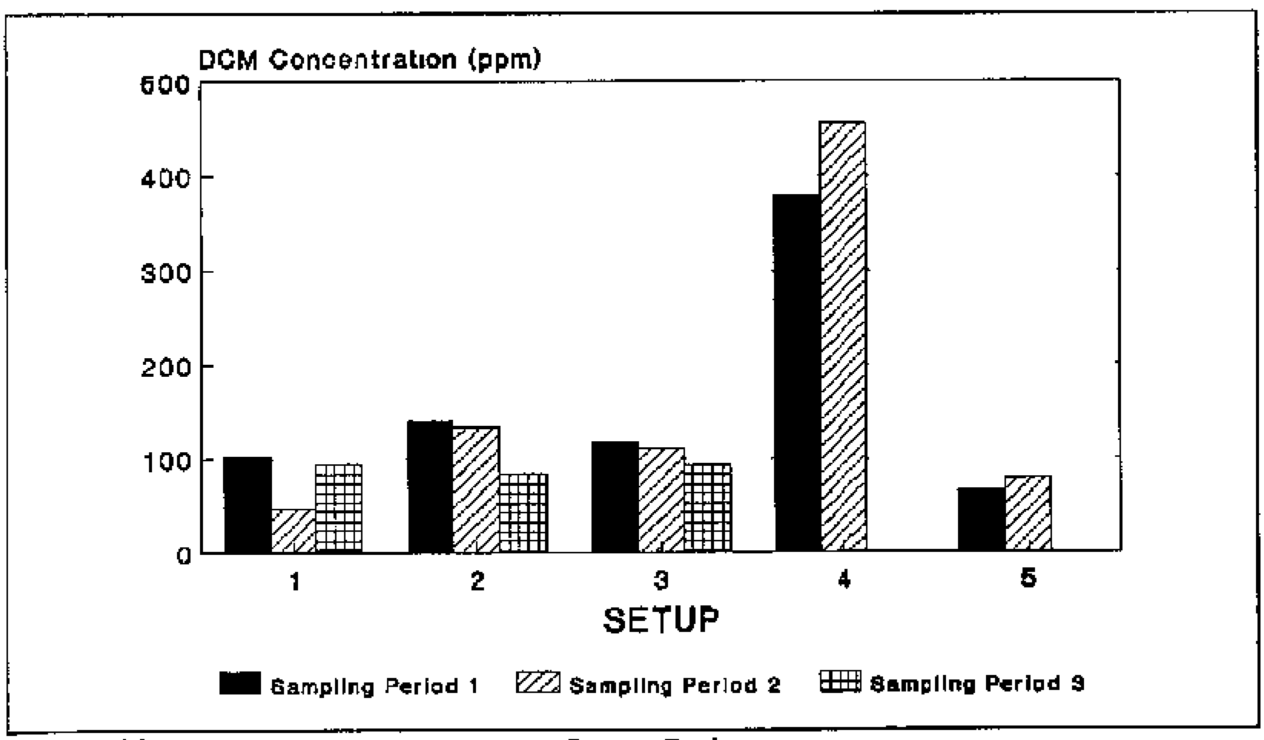


Figure 13 DCM Concentration at Rinse Tank

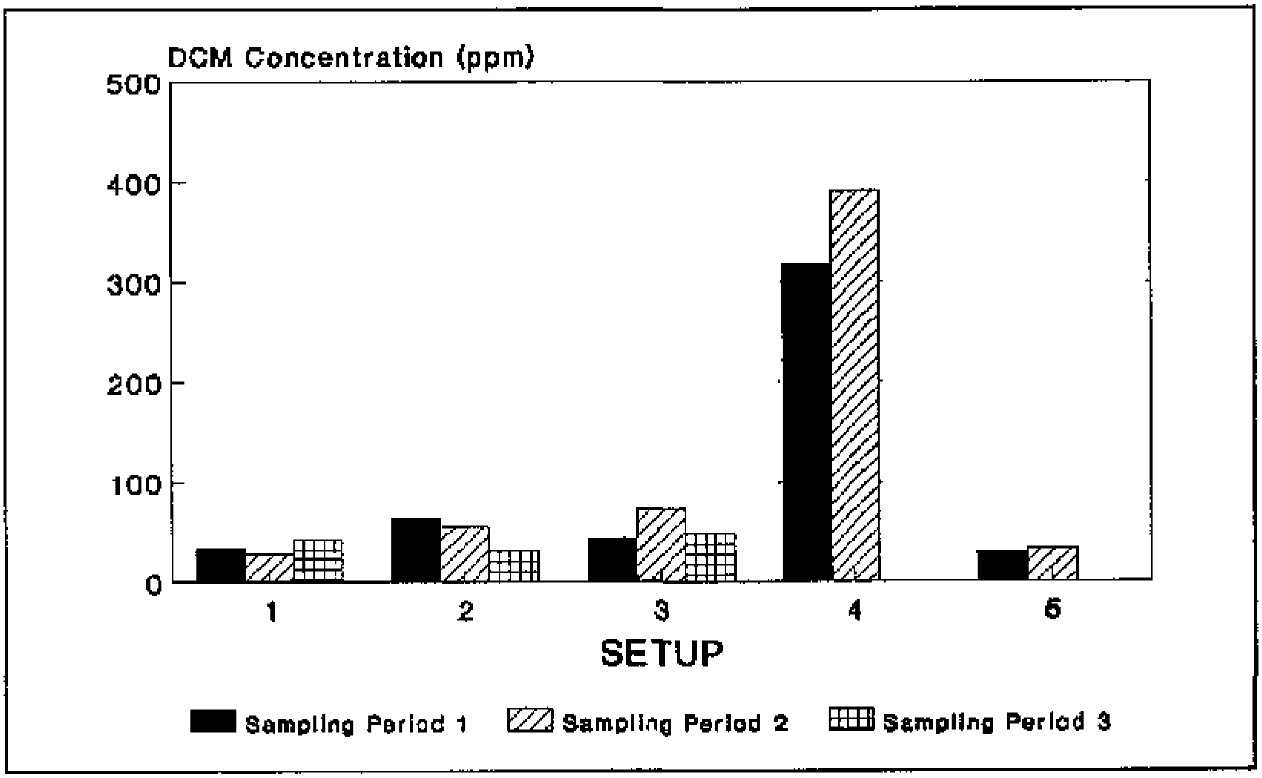


Figure 14 DCM Concentration at Back Wall

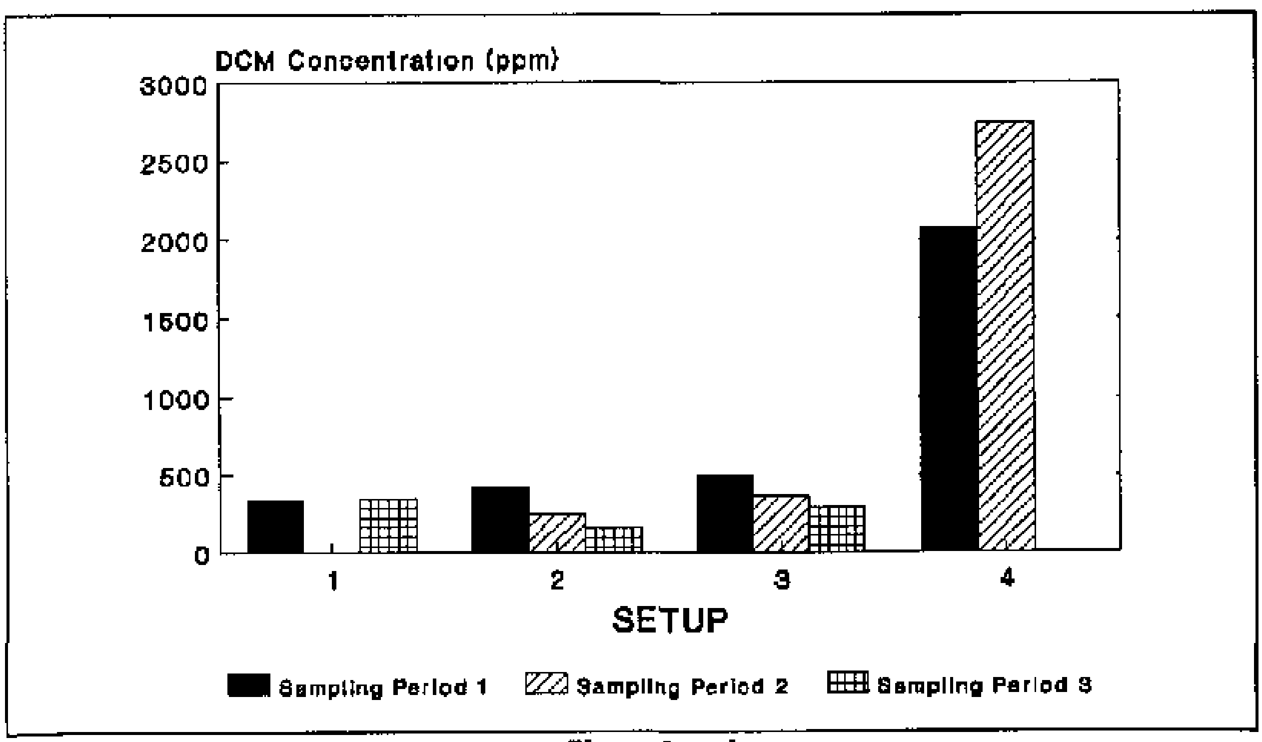


Figure 15 DCM Concentration at Floor Level

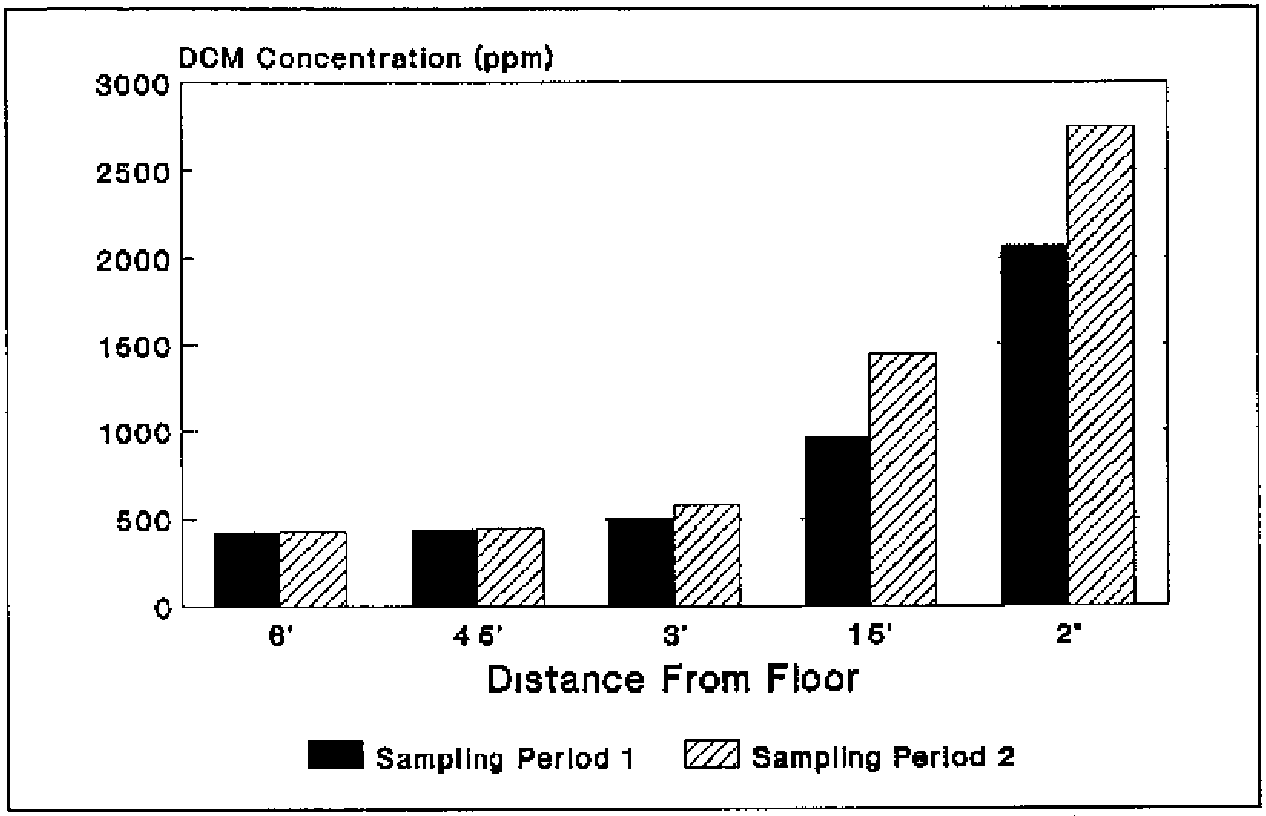


Figure 16 DCM Concentration at Different Heights During Setup 4

ventilation systems averaged close to 40 ppm While personal methanol exposures during Setups 4 and 5 averaged 84 ppm and 56 ppm, respectively The methanol exposures are shown in Figure 17 Appendix A shows sorbent sampling tube results for all methylene chloride and methanol tubes taken

Air velocity measurements were taken on each hood to estimate the volume of air the tank was exhausting The hood ventilation system, Setup 1, collected fresh air from the top and front openings in the tank The velocity of the air entering across these planes was measured using the Kurz digital air velocity meter The average air velocity across the front plane was 19 feet per minute (fpm) and that of the top was 16 fpm The amount of air going into the tank at the front and top may not be enough to overcome random air currents Using these velocity measurements, the average amount of air exhausted from the tank is 1,000 cubic feet per minute (cfm)

The exhaust volume from the PVC pipe, Setup 2, is approximately 1,000 cfm, averaged using velocities from the openings of the two PVC pipes The velocity at the two openings of the ducts was about 600 fpm The average velocity measured across the top plane of the tank was approximately 8 fpm, which is not significant in comparison to the scale measured (0 to 500 fpm) The one-third of the tank closest to the PVC pipe had higher air velocities, while the rest of the tank had very low velocities However, all of the air velocities at the tank level were below 50 fpm, which is less than random air

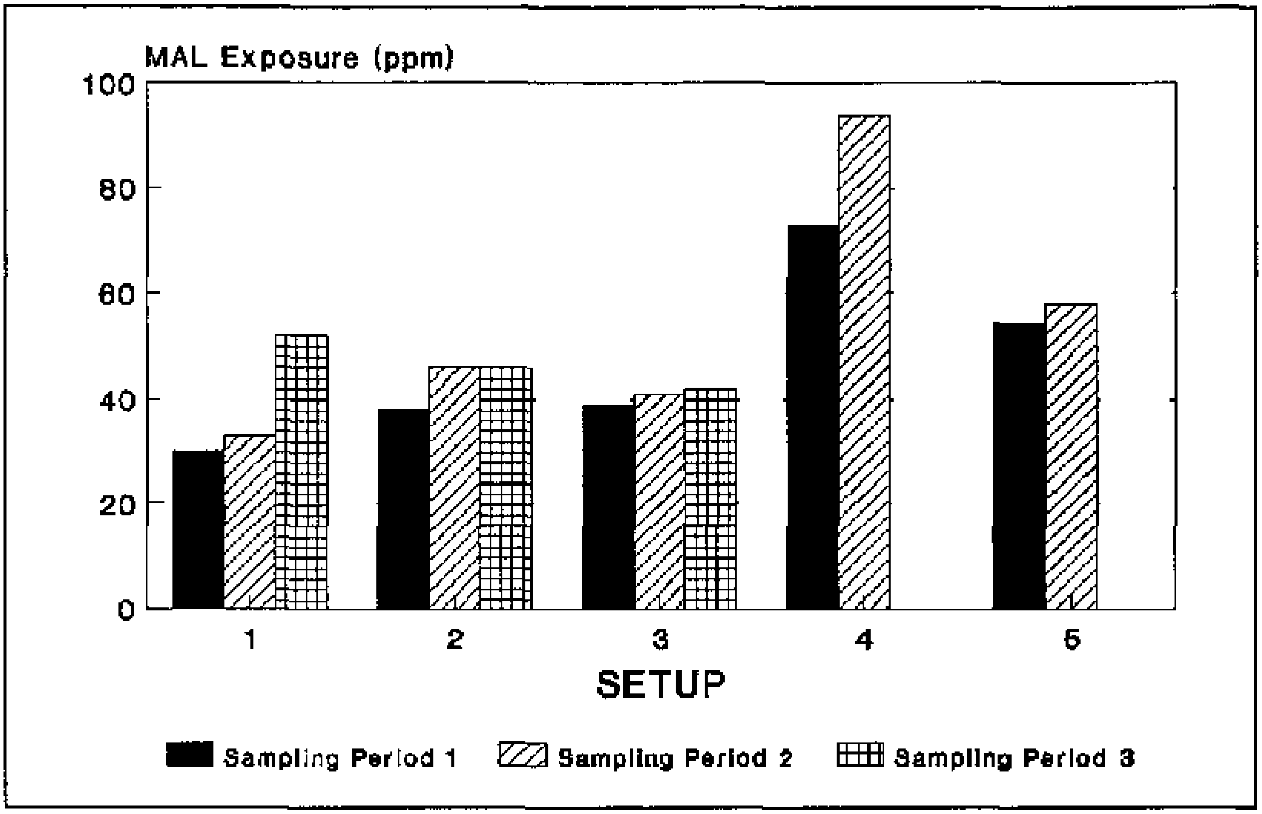


Figure 17 Personal Exposure to Methanol

A circular hood opening will have a velocity less than 7 5% of the velocity at the opening one diameter from the opening [20] Therefore, for the 6-inch ductwith 600 fpm velocity at the opening will have a velocity of less than 45 fpm at 6 inches from the opening

The floor ventilation system, Setup 3, was being used for dilution ventilation rather than local ventilation because the methylene chloride concentrations had to travel from the source down to the floor before being exhausted The opening of the plenum exhausted about 1,400 cfm of air This is the highest volume of air exhausted shown from the three local ventilation systems However, the location of this hood is on the floor behind the tank, therefore, it is not as close to the generation of the concentration of methylene chloride

A flow-over® tank with no local ventilation (Setup 4) was the control situation This setup was run to have a baseline in which to compare other runs

The fifth setup used the floor ventilation system as in Setup 3, except the temperature of the furniture stripping solution was lowered by placing the stripping solution pail in ice

The weight of the solution was recorded for each setup in order to determine if the ventilation system had any effect on how much solution was used while stripping The weights were recorded before and after a setup and also before and after adding solution during a setup From the weights recorded, the amount of solution used was computed Table B shows the weight and volume of solution used during each setup There is not enough information to determine if the ventilation system had any effect on the amount of solution used, because there is only one repetition of the data for the setups which were quite different Although not conclusive for showing differences among ventilation systems, this data does show approximately how much solution is needed to strip chairs

Table B Amount of Solution Used for Each Setup

| Ventilation System | Number of Chairs Stripped | Weight of Solution Used | Approximate Volume of Solution Used |
|---|---|---|---|
| Hood | 9 | 28 lb 15 5 oz | 3 0 gal |
| PVC Pipe | 9 | - | - |
| Floor | 9 | 21 lb 7 5 oz | 2 2 gal |
| Control | 6 | 25 lb 10 5 oz | 2 6 gal |
| Floor (Low Soln Temp) | 6 | 18 lb 1 oz | 1 8 gal |

STATISTICAL ANALYSIS

For each sampling period, data was obtained for personal exposure, and for area samples located at the back wall, the floor, the flow-over® tank, and the rinse tank Objectives of the statistical analysis were to compare methylene chloride and methanol exposure levels for the three ventilation systems used in Setups 1, 2, and 3 to each other and to the control or general ventilation system, Setup 4, to determine how each compared to environmental criteria, and to see if there was a difference associated with the temperature of the solution The data included personal and area samples at four locations for each sampling period of each setup In each case, a separate analysis was done for the area sample data and the personal sample data because the personal sample data is the most important information for determining exposures

The breathing zone and area samples for methylene chloride were taken using a modified NIOSH Method 1005 Two 100/50 mg charcoal sorbent tubes were used in series, therefore, for each sample taken there was a front and a back value Most of the back samples were reported as "non-detectable" (ND) by the analytical laboratory The data was analyzed in two ways (1) By using the analytical laboratory's reported limit of detection divided by 2,[21] and (2) By ignoring the values reported as "non-detectable " While the first method's analysis yielded slightly more precise results with lower levels of statistical significance (i e , "more" significant), there were no substantial differences in conclusions  Results for the first method of treatment are reported here  The breathing zone and area samples for methanol were taken using NIOSH Method 2000

Methylene Chloride Concentrations

Personal samples taken in the breathing zone of the worker were looked at more closely than any of the area samples because they are directly related to worker exposures  For the methylene chloride data, the observed levels for Setups 1, 2, and 3 did not differ to a statistically significant extent, but the three were statistically significantly different from Setup 4 at the 0 05 level using the Scheffe' method for evaluating differences among all four setups  For Setups 1, 2, and 3, the concentrations the worker was exposed to was under the OSHA PEL  However, these levels were higher than the ACGIH TLV of 50 ppm  Also, it is not believed that these levels meet the lowest feasible limit guideline NIOSH has set for methylene chloride  Ninety five percent simultaneous confidence interval estimates of the level of methylene chloride by setup are shown in Table C

| Table C  Personal Exposure to Methylene Chloride by Setup | | | | |
|---|---|---|---|---|
| 95 Percent Simultaneous Confidence Intervals | | | | |
| Setup | Ventilation System | Lower Limit | Point | Upper Limit |
| 1 | Hood | 147 | 227 | 352 |
| 2 | PVC Pipe | 125 | 193 | 298 |
| 3 | Floor | 137 | 212 | 328 |
| 4 | Control | 351 | 599 | 1022 |

Setup 4 is over the OSHA PEL, as well as the ACGIH TLV (the upper nonsimultaneous confidence limit, not shown, is greater than 500 ppm)  This setup was run as a control for comparison to the systems with local ventilation

The area samples located at the flow-over® tank, the rinse tank, the floor, and the back wall were used to compare the ventilation system's ability to dilute the amount of methylene chloride in the room  There is at least one difference among the four setups which is statistically significant ($p< 0088$) Using the Scheffe' method of multiple comparisons, differences between Setup 4 and Setups 1, 2, and 3 are significant  However, differences among Setups 1, 2, and 3 are not significant using the least significant difference method None of the differences among Setups 1, 2, and 3 reached the 0 05 nonsimultaneous level for significance  Simultaneous 95% confidence interval estimates for levels of methylene chloride for each setup criteria are shown in Table D

There is at least one difference in methylene chloride levels among locations which is statistically significant ($p<0.0003$). The area sample at the floor level is significantly higher than the other three locations. Differences among area samples at the rinse tank, the flow tank, and the back wall are not statistically significant, using the Ryan-Einot-Gabrial-Welsh Multiple F-Test [22]. Simultaneous confidence interval estimates for the level of methylene chloride at each location are shown in Table E for the average over the four setups.

| Table D  Area Concentrations of Methylene Chloride by Setup | | | | | |
|---|---|---|---|---|---|
| Area Sample Data - Averaged over Four Areas | | | | | |
| 95 Percent Simultaneous Confidence Intervals | | | | | |
| Setup | Ventilation System | Number of Observations | Lower Limit | Mean | Upper Limit |
| 1 | Hood | 12 | 21 | 68 | 221 |
| 2 | PVC Pipe | 12 | 30 | 98 | 318 |
| 3 | Floor | 12 | 37 | 120 | 390 |
| 4 | Control | 8 | 158 | 667 | 2823 |

| Table E  Estimated Area Concentrations of Methylene Chloride | | | |
|---|---|---|---|
| Simultaneous 95 Percent Scheffe' Confidence Intervals | | | |
| Location | Lower Limit | Mean | Upper Limit |
| Floor | 156 | 308 | 610 |
| Rinse Tank | 67 | 132 | 262 |
| Flow-Over® Tank | 51 | 101 | 199 |
| Back Wall | 35 | 69 | 136 |
| N = 11 observations in each case | | | |

Because both the type of ventilation and the location within the stripping area were found to be statistically significant factors, estimated levels of methylene chloride would depend on both the setup and the location. Ninety five percent simultaneous confidence interval estimates for each combination of setup and location are shown in Table F. See Appendix B for a description of the methods used to obtain these values.

| Table F  Estimated Methylene Chloride Concentrations by Setup and Location | | | | | |
|---|---|---|---|---|---|
| 95 Percent Bonferroni Intervals | | | | | |
| Setup | Ventilation System | Sample Location | Lower Limit | Point | Upper Limit |
| 1 | Hood | Back Wall | 11 | 37 | 121 |
| 1 | Hood | Floor | 49 | 164 | 544 |
| 1 | Hood | Flow-Over® Tank | 16 | 54 | 178 |
| 1 | Hood | Rinse Tank | 21 | 70 | 234 |
| 2 | PVC Pipe | Back Wall | 16 | 53 | 175 |
| 2 | PVC Pipe | Floor | 71 | 236 | 783 |
| 2 | PVC Pipe | Flow-Over® Tank | 23 | 77 | 256 |
| 2 | PVC Pipe | Rinse Tank | 31 | 101 | 336 |
| 3 | Floor | Back Wall | 19 | 65 | 214 |
| 3 | Floor | Floor | 87 | 290 | 960 |
| 3 | Floor | Flow-Over® Tank | 29 | 95 | 314 |
| 3 | Floor | Rinse Tank | 38 | 124 | 413 |
| 4 | Control | Back Wall | 83 | 361 | 1569 |
| 4 | Control | Floor | 373 | 1619 | 7029 |
| 4 | Control | Flow-Over® Tank | 122 | 529 | 2298 |
| 4 | Control | Rinse Tank | 160 | 696 | 3020 |
| Note  The values in this table my appear inconsistent with those in Tables D and E because all three tables used nonlinear transformation of estimates for the log transformed data | | | | | |

COMPARISON OF SETUPS 3 AND 5 FOR METHYLENE CHLORIDE

Setups 3 and 5 can be compared for the area samples taken at back wall, flow-over® tank, and rinse tank and for personal samples  Setup 5 was identical to Setup 3, which used floor ventilation, except that the stripping solution bucket was put in ice water to cool it  Thus, the comparison of Setup 5 to Setup 3 should test the hypothesis that cooling the solution makes no difference for exposure while the alternative is that exposures are affected by the temperature of the cooling solution  While it was hypothesized that cooling would reduce exposure, a two-sided test is used in case the actual effect is that cooling increases exposure

Since all results were virtually identical whether the log transform was or was not used, results for the original scale are presented  The setup by location interaction was not significant (p<0 54), which makes the test for setup differences unbiased

For the personal samples, Setup 5 had an estimated mean exposure of 374 ppm, which was significantly (p<0 01) higher than the estimated 213 ppm for Setup 3  The 95% confidence interval for the difference ranged from 72 ppm to 250 ppm with a mean of 161 ppm  Thus, exposures for the cooled stripping solution were higher than when the stripping solution was warmed  Personal sample exposure differences for solution temperature differences are shown in Table G

| Table G  Personal Exposures to Methylene Chloride by Temperature of Stripping Solution | | | | |
|---|---|---|---|---|
| Sheffe's Confidence Intervals (95%) | | | | |
| Setup | Average Temperature °F | Simultaneous Lower Confidence Limit | Mean | Simultaneous Upper Confidence Limit |
| 3 | 70 | 135 | 213 | 290 |
| 5 | 63 | 279 | 374 | 469 |

Methylene chloride concentrations for areas were lower for Setup 5 than for Setup 3 (p<0 045)  The mean difference estimate was 26 7 ppm while the 95 percent confidence interval ranges from 0 01 ppm to 53 ppm  Confidence interval estimates of exposure are shown by setup in Table H

| Table H  Area Methylene Chloride Exposure Levels by Temperature of Stripping Solution | | | | |
|---|---|---|---|---|
| 95 Percent Non-Simultaneous Intervals in PPM | | | | |
| Setup | Temperature | Lower Confidence Limit | Mean | Upper Confidence Limit |
| 3 | warm | 65 | 82 | 99 |
| 5 | cool | 34 | 55 | 76 |

Differences among the three sampling locations were also statistically significant (p<0 0007) and all pairwise differences among them were also simultaneously significant using the Tukey method [23]  The simultaneous 95% confidence intervals (using the Scheffe' method) are shown in Table I  The rinse tank recorded the highest concentration at 95 ppm, followed by flow-over® tank with 70 ppm, while back wall was lowest at 48 ppm

Simultaneous confidence interval estimates for each setup and by each sampling location are shown in Table J

METHANOL CONCENTRATIONS

There is at least one difference among Setups 1, 2, 3, and 4 (the control) on methanol concentrations recorded by the personal samplers which were statistically significant (p<0 002) None of the contrasts - pairwise or otherwise - among the three modified setups, i e , Setups 1, 2, and 3, were significant using even the most liberal tests at the 0 05 significance level However, all pairwise contrasts between the control and the three modified setups were simultaneously significant at the 0 05 level using the conservative Scheffe' multiple comparison method Simultaneous confidence intervals are shown in Table K for all four setups and Setup 5

| Table I Estimated Methylene Chloride Levels by Sampling Location | | | |
|---|---|---|---|
| 95 Percent Simultaneous Confidence Intervals (Scheffe' Method) in PPM | | | |
| Location | Simultaneous Lower Confidence Limit | Mean | Simultaneous Upper Confidence Limit |
| Rinse Tank | 79 | 95 | 111 |
| Flow-Over® Tank | 54 | 70 | 86 |
| Back Wall | 32 | 48 | 64 |

COMPARISON OF SETUPS 3 AND 5 FOR METHANOL

The stripping solution was warm for Setup 3 and cool for Setup 5 The estimated personal sampler methanol concentrations for Setup 3 was 45 ppm, significantly lower than that for Setup 5 at 67 ppm (p<0 006) Simultaneous confidence intervals for the two setups are shown in Table K

DISCUSSION

Personal exposures to methylene chloride while using local ventilation systems were about 200 ppm, while stripping which was lower than the control system which used no local ventilation and had an average exposure of 600 ppm No differences were found among the three local ventilation systems tested in the level of personal exposure to methylene chloride and methanol Therefore, the systems with local ventilation were shown to be better for the worker by reducing their exposures Personal exposures to methylene chloride for the setups using local ventilation were under the OSHA PEL of 500 ppm However, the exposure levels were higher than the ACGIH TLV of 50 ppm and these levels do not meet the NIOSH recommendation of the lowest feasible limit

| Table J Estimated Methylene Chloride levels by Setup and Location in PPM | | | | | | |
|---|---|---|---|---|---|---|
| 95 Percent Simultaneous Bonferroni Intervals | | | | | | |
| Setup | Ventilation | Temperature | Location | Lower Limit | Point | Upper Limit |
| 3 | Floor | warm | Back Wall | 33 | 58 | 84 |
| 3 | Floor | warm | Flow-Over® Tank | 55 | 81 | 106 |
| 3 | Floor | warm | Rinse Tank | 80 | 106 | 131 |
| 5 | Floor | Cool | Back Wall | 0 | 32 | 63 |
| 5 | Floor | Cool | Flow-Over® Tank | 23 | 54 | 85 |
| 5 | Floor | Cool | Rinse Tank | 48 | 79 | 110 |

| Table K Estimated Methanol Personal Exposure Concentrations | | | | | |
|---|---|---|---|---|---|
| 95 Percent Simultaneous Confidence Intervals in PPM | | | | | |
| Setup | Ventilation | N | Simultaneous Lower Confidence Limit | Mean | Simultaneous Upper Confidence Limit |
| 1 | Hood | 3 | 24 | 45 | 67 |
| 2 | PVC Pipe | 3 | 28 | 50 | 71 |
| 3 | Floor | 3 | 23 | 45 | 66 |
| 4 | Control | 2 | 67 | 94 | 120 |
| 5 | Floor | 2 | 40 | 67 | 93 |

No control system was demonstrably better than any of the others One explanation is that approximately the same amount of air was being exhausted from the area in each of these cases Even though these local ventilation systems are better than the general ventilation system, they should not be considered adequate ventilation systems for the furniture stripping industry Methylene chloride exposures might be further reduced by exhausting a higher volume of air through local ventilation In this study, only chairs were stripped, other larger pieces of furniture or those with a more difficult finish to strip may increase the exposures that were shown here

The hood ventilation system might be the local ventilation system offering the most promise of those shown here for further reduction of methylene chloride exposures The system has the ability to exhaust uniformly around the entire tank as opposed to the PVC pipe ventilation system which will only exhaust one side of the tank Also, the hood ventilation system when exhausting enough air will confine the highest concentration of methylene chloride at the source Therefore, the methylene chloride vapors will be generated and exhausted at the same location The hood will be able to exhaust the methylene chloride vapors before they have a chance to reach the worker's breathing zone, as opposed to the floor ventilation system Increasing the amount of air exhausted should lower personal exposures to methylene chloride to improve this ventilation system Increasing the exhaust volume to about 2,000 cubic feet per minute (cfm) should be sufficient for the flow-over® tank area A rule of thumb is 50 fpm for each square foot of tank or 1,600 cfm for this tank However, a slightly higher exhaust volume is recommended because the front middle of the tank is so far from any of the slots Another way to improve this system may be to cover the top of the hood With the top covered, clean air moving into the exhaust system will be coming from the front side where the worker is standing The worker will then be in a clean air stream which will limit his exposure to methylene chloride

The PVC pipe system for local ventilation was shown in this case to be comparable to the hood ventilation system or the floor ventilation system However, adding more air to the PVC pipe system will not reduce exposures much because the middle and other end of the tank will not be effected Also, at one diameter from the opening of each duct, the air velocity is only 7 5% of what it was at the opening Therefore, the amount of air exhausted would have to be increased more than is feasible in order to exhaust methylene chloride vapors at the same rate they are generated

The floor ventilation system is able to keep up with the other two local ventilation systems as far as exposure to methylene chloride to the worker However, in order to further decrease the worker's exposure, this system is probably not a good alternative by itself The main problem is that before the methylene chloride vapors can be exhausted from the floor, they have to move from the source to the floor Therefore, there will be some concentration of methylene chloride in the breathing zone

If the hood system seems to be too confining for the different types of furniture being stripped, another recommendation is to look at a new ventilation system design which exhausts more air than those systems tested in this study A downdraft or slot hood system may be an alternative Figure 18 shows a combination of a tank with both a downdraft system and a slothood system As long as the system is pulling enough air, one of these systems may be sufficient

Setup 3 had lower levels of personal methylene chloride methanol exposures than Setup 5 However, the area concentrations were higher for Setup 3 The personal exposures and the area concentrations do not agree in this case The

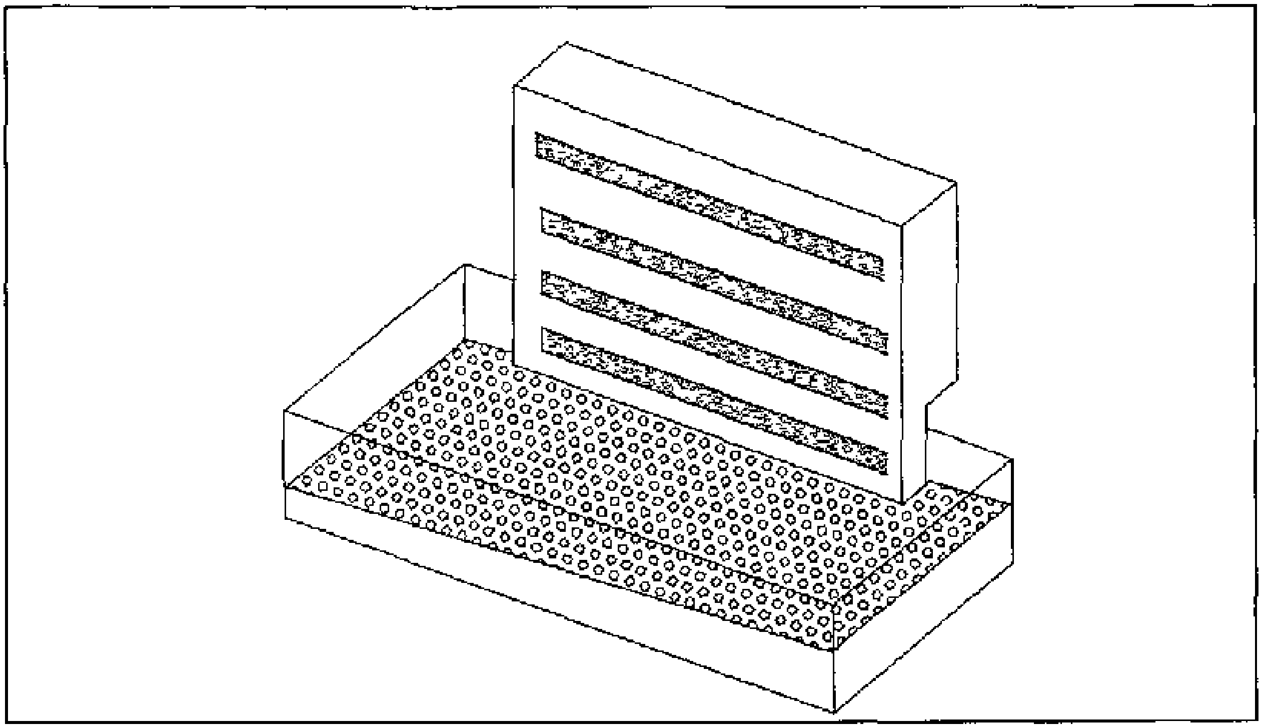

Figure 18    Combined Downdraft and Slothood Ventilation System

two setups were identical, except that the stripping solution was cooled to a lower temperature for Setup 5  The temperature for Setup 3 remained almost constant at 70 °F, while Setup 5 was cooled from 70 to 56 °F  For all setups except five, the solution was kept in a bucket with a heating belt around it  When the solution is cooled the wax, which is normally a vapor retardant, thickens and precipitates  This thickening of the wax may cause the stripping process to take longer and the solution to evaporate faster because the wax does not work as well as a retardant  This study was done in the summer, therefore, putting the solution on ice was not excessive because this approximated normal conditions for winter months without a heating belt  The personal exposures which were higher while the solution was being cooled using ice may have occurred because of the worker's added attention to the solution  This attentiveness to the solution might explain why the personal sample data and the area sample data show opposite results  More information is needed to show whether or not the temperature of the solution consistently increases or decreases worker exposure and room concentration

It was shown that concentrations at the floor level were higher than in any other area regardless of the ventilation system  This concentration may be exaggerated because many times the worker spilled or dripped some solution onto the floor possibly near where the sample was being taken  When concentrations are high in the room, generally more of the methylene chloride will gravitate to the floor  However, the intent of installing local ventilation systems is to capture the methylene chloride concentrations at the source before it has a chance to move towards the floor or move about the room and possibly into the breathing zone of the worker  Instead of considering ventilating the floor where concentrations may be higher, the source should be significantly ventilated to prevent high exposures on the floor or in the breathing zone of the worker

CONCLUSIONS

Three local ventilation systems for furniture stripping have been compared to general ventilation for worker's exposure to methylene chloride All of these local ventilation systems (Setups 1, 2, and 3) were shown to be an improvement over general dilution ventilation Stripping furniture without local ventilation (Setup 4) is above the OSHA PEL and the ACGIH TLV Also, it is believed that these levels do not meet the lowest feasible limit guideline NIOSH has set for methylene chloride With the local ventilation systems used in this study, it is easy to accomplish the stripping according to the OSHA PEL of 500 ppm However, 500 ppm exposure to methylene chloride is not considered safe by NIOSH The local ventilation systems considered here should be improved in order to lower the personal exposures methylene chloride to safer levels Increasing the amount of air exhausted local from the stripping area is an easy alternative which might significantly reduce exposures to methylene chloride, as well as enclosing the tank and other tank and ventilation system designs

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## APPENDIX A: SORBENT SAMPLING DATA

| SETUP | PERSON/ LOCATION CODE | TIME (min) | VOLUME (liters) | METHANOL (mg/m3) | METHANOL (ppm) | METHYLENE CHLORIDE (mg/m3) | METHYLENE CHLORIDE (ppm) |
|---|---|---|---|---|---|---|---|
| 1 | RINSE RT 5' | 37 | 0 7 | 53 | 41 | | |
| 1 | RINSE RT 5' | 45 | 0 9 | <21 93 | <16 73 | | |
| 1 | RINSE RT 5' | 50 | 1 0 | <19 73 | <15 06 | | |
| 1 | RINSE RT 5' | 37 | 0 7 | | | 355 | 102 |
| 1 | RINSE RT 5' | 37 | 0 7 | | | <13 66 | <3 93 |
| 1 | RINSE RT 5' | 46 | 0 9 | | | 165 | 47 |
| 1 | RINSE RT 5' | 46 | 0 9 | | | <10 99 | <3 16 |
| 1 | RINSE RT 5' | 49 | 1 0 | | | 325 | 94 |
| 1 | RINSE RT 5' | 49 | 1 0 | | | <15 00 | <2 92 |
| 1 | FLOW RT 5' | 32 | 0 6 | <30 79 | <23 49 | | |
| 1 | FLOW RT 5' | 47 | 1 0 | 21 | 16 | | |
| 1 | FLOW RT 5' | 53 | 1 1 | 19 | 14 | | |
| 1 | FLOW RT 5' | 32 | 0 6 | | | 297 | 85 |
| 1 | FLOW RT 5' | 32 | 0 6 | | | <15 63 | <4 50 |
| 1 | FLOW RT 5' | 47 | 0 9 | | | 255 | 74 |
| 1 | FLOW RT 5' | 47 | 0 9 | | | <10 64 | <3 06 |
| 1 | FLOW RT 5' | 53 | 1 1 | | | 330 | 95 |
| 1 | FLOW RT 5' | 53 | 1 1 | | | <9 44 | <2 72 |
| 1 | BACKWALL 6' | 34 | 0 7 | <29 69 | <22 66 | | |
| 1 | BACKWALL 6' | 46 | 0 9 | <21 95 | <16 75 | | |
| 1 | BACKWALL 6' | 51 | 1 0 | <19 80 | <15 11 | | |
| 1 | BACKWALL 6' | 34 | 0 7 | | | 120 | 35 |
| 1 | BACKWALL 6' | 34 | 0 7 | | | <15 05 | <4 33 |
| 1 | BACKWALL 6' | 46 | 0 9 | | | 100 | 29 |
| 1 | BACKWALL 6' | 46 | 0 9 | | | <11 13 | <3 20 |
| 1 | BACKWALL 6' | 51 | 1 0 | | | 151 | 43 |
| 1 | BACKWALL 6' | 51 | 1 0 | | | <10 03 | <2 89 |
| 1 | PLENUM | 35 | 0 7 | | | 2243 | 646 |
| 1 | PLENUM | 35 | 0 7 | | | <14 02 | <4 04 |
| 1 | PLENUM | 44 | 0 9 | | | 1673 | 482 |
| 1 | PLENUM | 44 | 0 9 | | | <11 15 | <3 21 |

| SETUP | PERSON/ LOCATION CODE | TIME (min) | VOLUME (liters) | METHANOL (mg/m3) | METHANOL (ppm) | METHYLENE CHLORIDE (mg/m3) | METHYLENE CHLORIDE (ppm) |
|---|---|---|---|---|---|---|---|
| 1 | PLENUM | 54 | 1 1 | | | 2181 | 628 |
| 1 | PLENUM | 54 | 1 1 | | | <9 09 | <2 62 |
| 1 | FLOW FLOOR 2″ | 35 | 0 7 | | | 686 | 197 |
| 1 | FLOW FLOOR 2″ | 35 | 0 7 | | | 496 | 143 |
| 1 | FLOW FLOOR 2″ | 45 | 0 9 | | | <11 35 | <3 27 |
| 1 | FLOW FLOOR 2″ | 45 | 0 9 | | | <11 35 | <3 27 |
| 1 | FLOW FLOOR 2″ | 51 | 1 0 | | | 1202 | 346 |
| 1 | FLOW FLOOR 2″ | 51 | 1 0 | | | <10 01 | <2 88 |
| 1 | FLOW CEILING | 39 | 0 8 | | | 113 | 33 |
| 1 | FLOW CEILING | 39 | 0 8 | | | <12 57 | <3 62 |
| 1 | FLOW CEILING | 44 | 0 9 | | | 145 | 42 |
| 1 | FLOW CEILING | 44 | 0 9 | | | <11 14 | <3 21 |
| 1 | FLOW CEILING | 51 | 1 0 | | | 173 | 50 |
| 1 | FLOW CEILING | 51 | 1 0 | | | <9 61 | <2 77 |
| 1 | PERSONAL | 38 | 0 8 | 39 | 30 | | |
| 1 | PERSONAL | 45 | 0 9 | 44 | 33 | | |
| 1 | PERSONAL | 43 | 0 9 | 68 | 52 | | |
| 1 | PERSONAL | 38 | 0 8 | | | 682 | 196 |
| 1 | PERSONAL | 38 | 0 8 | | | <12 87 | <3 71 |
| 1 | PERSONAL | 44 | 0 9 | | | 689 | 198 |
| 1 | PERSONAL | 44 | 0 9 | | | <11 12 | <3 20 |
| 1 | PERSONAL | 43 | 0 9 | | | 751 | 216 |
| 1 | PERSONAL | 43 | 0 9 | | | 262 | 75 |
| 2 | FLOW FLOOR 6″ | 39 | 0 7605 | | | 1446 | 416 |
| 2 | FLOW FLOOR 6″ | 39 | 0 7605 | | | <13 15 | <3 79 |
| 2 | FLOW FLOOR 6″ | 59 | 1 1505 | | | 869 | 250 |
| 2 | FLOW FLOOR 6″ | 59 | 1 1505 | | | <8 69 | <2 50 |
| 2 | FLOW FLOOR 6″ | 57 | 1 1115 | | | 540 | 155 |
| 2 | FLOW FLOOR 6″ | 57 | 1 1115 | | | <9 00 | <2 59 |
| 2 | FLOW RT 5' | 36 | 0 7308 | 14 | 10 | | |

| SETUP | PERSON/ LOCATION CODE | TIME (min) | VOLUME (liters) | METHANOL (mg/m3) | METHANOL (ppm) | METHYLENE CHLORIDE (mg/m3) | METHYLENE CHLORIDE (ppm) |
|---|---|---|---|---|---|---|---|
| 2 | FLOW RT 5' | 59 | 1 1977 | 17 | 13 | | |
| 2 | FLOW RT 5' | 59 | 1 1977 | <16 70 | <12 74 | | |
| 2 | FLOW RT 5' | 36 | 0 70344 | | | 256 | 74 |
| 2 | FLOW RT 5' | 36 | 0 70344 | | | <14 22 | <4 09 |
| 2 | FLOW RT 5' | 59 | 1 5286 | | | 183 | 53 |
| 2 | FLOW RT 5' | 59 | 1 5286 | | | <6 54 | <1 88 |
| 2 | FLOW RT 5' | 59 | 1 5286 | | | 124 | 36 |
| 2 | FLOW RT 5' | 59 | 1 5286 | | | <6 54 | <1 88 |
| 2 | PLENUM | 39 | 0 80535 | | | 11672 | 3360 |
| 2 | PLENUM | 39 | 0 80535 | | | <12 42 | <3 57 |
| 2 | PLENUM | 59 | 1 21835 | | | 9849 | 2835 |
| 2 | PLENUM | 59 | 1 21835 | | | <8 21 | <2 36 |
| 2 | PLENUM | 56 | 1 1564 | | | 14701 | 4232 |
| 2 | PLENUM | 56 | 1 1564 | | | 130 | 37 |
| 2 | RINSE RT 5' | 35 | 0 69965 | | | 486 | 140 |
| 2 | RINSE RT 5' | 35 | 0 69965 | | | <14 29 | <4 11 |
| 2 | RINSE RT 5' | 59 | 1 17941 | | | 466 | 134 |
| 2 | RINSE RT 5' | 59 | 1 17941 | | | <8 48 | <2 44 |
| 2 | RINSE RT 5' | 59 | 1 17941 | | | 288 | 83 |
| 2 | RINSE RT 5' | 59 | 1 17941 | | | <8 48 | <2 44 |
| 2 | RINSE RT 5' | 35 | 0 6853 | 29 | 22 | | |
| 2 | RINSE RT 5' | 59 | 1 15522 | 43 | 33 | | |
| 2 | RINSE RT 5' | 59 | 1 15522 | 26 | 20 | | |
| 2 | BACK WALL 6' | 36 | 0 7236 | | | 221 | 64 |
| 2 | BACK WALL 6' | 36 | 0 7236 | | | <13 82 | <3 98 |
| 2 | BACK WALL 6' | 60 | 1 206 | | | 191 | 55 |
| 2 | BACK WALL 6' | 60 | 1 206 | | | <8 29 | <2 39 |
| 2 | BACK WALL 6' | 60 | 1 206 | | | 108 | 31 |
| 2 | BACK WALL 6' | 60 | 1 206 | | | <8 29 | <2 39 |
| 2 | BACK WALL 6' | 36 | 0 7344 | <27 23 | <20 78 | | |
| 2 | BACK WALL 6' | 60 | 1 224 | 16 | 12 | | |

| SETUP | PERSON/ LOCATION CODE | TIME (min) | VOLUME (liters) | METHANOL (mg/m3) | METHANOL (ppm) | METHYLENE CHLORIDE (mg/m3) | METHYLENE CHLORIDE (ppm) |
|---|---|---|---|---|---|---|---|
| 2 | BACK WALL 6' | 60 | 1 224 | <16 34 | <12 47 | | |
| 2 | PERSONAL | 41 | 0 83804 | | | 656 | 189 |
| 2 | PERSONAL | 41 | 0 83804 | | | <11 93 | <3 43 |
| 2 | PERSONAL | 59 | 1 20696 | | | 779 | 224 |
| 2 | PERSONAL | 59 | 1 20696 | | | <8 29 | <2 38 |
| 2 | PERSONAL | 58 | 1 18552 | | | 565 | 163 |
| 2 | PERSONAL | 58 | 1 18552 | | | <8 44 | <2 43 |
| 2 | PERSONAL | 41 | 0 81221 | 49 | 38 | | |
| 2 | PERSONAL | 59 | 1 16879 | 60 | 46 | | |
| 2 | PERSONAL | 58 | 1 14898 | 61 | 46 | | |
| | | | | | | | |
| 3 | RINSE RT 5' | 44 | 0 87956 | | | 409 | 118 |
| 3 | RINSE RT 5' | 44 | 0 87956 | | | <11 37 | <3 27 |
| 3 | RINSE RT 5' | 48 | 0 95952 | | | 386 | 111 |
| 3 | RINSE RT 5' | 48 | 0 95952 | | | <10 42 | <3 00 |
| 3 | RINSE RT 5' | 48 | 0 95952 | | | 323 | 93 |
| 3 | RINSE RT 5' | 48 | 0 95952 | | | <10 42 | <3 00 |
| 3 | RINSE RT 5' | 44 | 0 86152 | 35 | 27 | | |
| 3 | RINSE RT 5' | 51 | 0 99858 | 40 | 31 | | |
| 3 | RINSE RT 5' | 45 | 0 8811 | 34 | 26 | | |
| 3 | FLOW RT 5' | 47 | 0 91838 | | | 261 | 75 |
| 3 | FLOW RT 5' | 47 | 0 91838 | | | <10 89 | <3 13 |
| 3 | FLOW RT 5' | 46 | 0 89884 | | | 300 | 86 |
| 3 | FLOW RT 5' | 46 | 0 89884 | | | <11 13 | <3 20 |
| 3 | FLOW RT 5' | 49 | 0 95746 | | | 240 | 69 |
| 3 | FLOW RT 5' | 49 | 0 95746 | | | <10 44 | <3 01 |
| 3 | FLOW RT 5' | 47 | 0 9541 | <20 96 | <16 00 | | |
| 3 | FLOW RT 5' | 50 | 1 015 | 20 | 15 | | |
| 3 | FLOW RT 5' | 45 | 0 9135 | 22 | 17 | | |
| 3 | FLOW FLOOR 2" | 48 | 0 936 | | | 1709 | 492 |
| 3 | FLOW FLOOR 2" | 48 | 0 936 | | | <10 68 | <3 08 |

| SETUP | PERSON/ LOCATION CODE | TIME (min) | VOLUME (liters) | METHANOL (mg/m3) | METHANOL (ppm) | METHYLENE CHLORIDE (mg/m3) | METHYLENE CHLORIDE (ppm) |
|---|---|---|---|---|---|---|---|
| 3 | FLOW FLOOR 2" | 49 | 0 9555 | | | 1256 | 362 |
| 3 | FLOW FLOOR 2" | 49 | 0 9555 | | | <10 47 | <3 01 |
| 3 | FLOW FLOOR 2" | 46 | 0 897 | | | 1003 | 289 |
| 3 | FLOW FLOOR 2" | 46 | 0 897 | | | <11 15 | <3 21 |
| 3 | BACK WALL 6' | 49 | 0 9849 | | | 152 | 44 |
| 3 | BACK WALL 6' | 49 | 0 9849 | | | <10 15 | <2 92 |
| 3 | BACK WALL 6' | 47 | 0 9447 | | | 254 | 73 |
| 3 | BACK WALL 6' | 47 | 0 9447 | | | 21 | 6 |
| 3 | BACK WALL 6' | 46 | 0 9246 | | | 162 | 47 |
| 3 | BACK WALL 6' | 46 | 0 9246 | | | <10 82 | <3 11 |
| 3 | BACK WALL 6' | 50 | 1 02 | <9 80 | <7 48 | | |
| 3 | BACK WALL 6' | 46 | 0 9384 | 21 | 16 | | |
| 3 | BACK WALL 6' | 46 | 0 9384 | <21 31 | <16 26 | | |
| 3 | PERSONAL | 50 | 1 022 | | | 802 | 231 |
| 3 | PERSONAL | 50 | 1 022 | | | <9 78 | <2 82 |
| 3 | PERSONAL | 47 | 0 96068 | | | 791 | 228 |
| 3 | PERSONAL | 47 | 0 96068 | | | <10 41 | <3 00 |
| 3 | PERSONAL | 46 | 0 94024 | | | 606 | 175 |
| 3 | PERSONAL | 46 | 0 94024 | | | <10 64 | <3 06 |
| 3 | PERSONAL | 50 | 0 9905 | 50 | 39 | | |
| 3 | PERSONAL | 47 | 0 93107 | 54 | 41 | | |
| 3 | PERSONAL | 46 | 0 91126 | 55 | 42 | | |
| | | | | | | | |
| 4 | RINSE RT 5' | 45 | 0 90135 | 55 | 42 | | |
| 4 | RINSE RT 5' | 46 | 0 92138 | 87 | 66 | | |
| 4 | RINSE RT 5' | 44 | 0 9086 | | | 1321 | 380 |
| 4 | RINSE RT 5' | 44 | 0 9086 | | | <11 01 | <3 17 |
| 4 | RINSE RT 5' | 46 | 0 9499 | | | 1579 | 455 |
| 4 | RINSE RT 5' | 46 | 0 9499 | | | <10 53 | <3 03 |
| 4 | FLOW RT 5' | 47 | 0 91838 | | | 1416 | 407 |
| 4 | FLOW RT 5' | 47 | 0 91838 | | | <10 89 | <3 13 |

| SETUP | PERSON/ LOCATION CODE | TIME (min) | VOLUME (liters) | METHANOL (mg/m3) | METHANOL (ppm) | METHYLENE CHLORIDE (mg/m3) | METHYLENE CHLORIDE (ppm) |
|---|---|---|---|---|---|---|---|
| 4 | FLOW RT 5' | 45 | 0 8793 | | | 1592 | 458 |
| 4 | FLOW RT 5' | 45 | 0 8793 | | | 23 | 7 |
| 4 | FLOW RT 5' | 47 | 0 9541 | 63 | 48 | | |
| 4 | FLOW RT 5' | 45 | 0 9135 | 77 | 58 | | |
| 4 | FLOW RT F 3'8" | 48 | 0 93984 | | | 1702 | 490 |
| 4 | FLOW RT F 3'8" | 48 | 0 93984 | | | <10 64 | <3 06 |
| 4 | FLOW RT F 3'8" | 46 | 0 90068 | | | 2443 | 703 |
| 4 | FLOW RT F 3'8" | 46 | 0 90068 | | | <11 10 | <3 2 |
| 4 | FLOW RT B 3'8" | 47 | 0 9353 | | | 2566 | 739 |
| 4 | FLOW RT B 3'8" | 47 | 0 9353 | | | <10 69 | <3 08 |
| 4 | FLOW RT B 3'8" | 46 | 0 9154 | | | 2622 | 755 |
| 4 | FLOW RT B 3'8" | 46 | 0 9154 | | | <10 92 | <3 14 |
| 4 | FLOW LT B 3'8" | 48 | 0 936 | | | 1816 | 523 |
| 4 | FLOW LT B 3'8" | 48 | 0 936 | | | <10 68 | <3 08 |
| 4 | FLOW LT B 3'8" | 44 | 0 858 | | | 2098 | 604 |
| 4 | FLOW LT B 3'8" | 44 | 0 858 | | | 163 | 47 |
| 4 | FLOW LT F 3'8" | 48 | 0 96096 | | | 1665 | 479 |
| 4 | FLOW LT F 3'8" | 48 | 0 96096 | | | <10 41 | <3 00 |
| 4 | FLOW LT F 3'8" | 44 | 0 88088 | | | 2270 | 654 |
| 4 | FLOW LT F 3'8" | 44 | 0 88088 | | | <11 35 | <3 27 |
| 4 | HEIGHT 6' | 49 | 0 9555 | | | 1465 | 422 |
| 4 | HEIGHT 6' | 49 | 0 9555 | | | 63 | 18 |
| 4 | HEIGHT 6' | 45 | 0 8775 | | | 1481 | 426 |
| 4 | HEIGHT 6' | 45 | 0 8775 | | | <11 40 | <3 28 |
| 4 | HEIGHT 4 5' | 49 | 0 98637 | | | 1521 | 438 |
| 4 | HEIGHT 4 5' | 49 | 0 98627 | | | <10 14 | <2 92 |
| 4 | HEIGHT 4 5' | 45 | 0 90585 | | | 1546 | 445 |
| 4 | HEIGHT 4 5' | 45 | 0 90585 | | | <11 04 | <3 18 |
| 4 | HEIGHT 3' | 50 | 0 97 | | | 1753 | 504 |
| 4 | HEIGHT 3' | 50 | 0 97 | | | <10 31 | <2 97 |
| 4 | HEIGHT 3' | 44 | 0 9 | | | 2000 | 576 |

| SETUP | PERSON/ LOCATION CODE | TIME (min) | VOLUME (liters) | METHANOL (mg/m3) | METHANOL (ppm) | METHYLENE CHLORIDE (mg/m3) | METHYLENE CHLORIDE (ppm) |
|---|---|---|---|---|---|---|---|
| 4 | HEIGHT 3' | 44 | 0 9 | | | <11 11 | <3 20 |
| 4 | HEIGHT 1 5' | 51 | 1 04244 | | | 3358 | 966 |
| 4 | HEIGHT 1 5' | 51 | 1 04244 | | | <9 59 | <2 76 |
| 4 | HEIGHT 1 5' | 44 | 0 89936 | | | 5004 | 1440 |
| 4 | HEIGHT 1 5' | 44 | 0 89936 | | | <11 12 | <3 20 |
| 4 | HEIGHT 2" | 50 | 1 0135 | | | 7203 | 2073 |
| 4 | HEIGHT 2" | 50 | 1 0135 | | | <9 87 | <2 84 |
| 4 | HEIGHT 2" | 45 | 0 91215 | | | 9538 | 2745 |
| 4 | HEIGHT 2" | 45 | 0 91215 | | | <10 96 | <3 16 |
| 4 | BACK WALL 6' | 45 | 0 9045 | | | 1106 | 318 |
| 4 | BACK WALL 6' | 45 | 0 9045 | | | <11 06 | <3 18 |
| 4 | BACK WALL 6' | 44 | 0 8844 | | | 1357 | 391 |
| 4 | BACK WALL 6' | 44 | 0 8844 | | | <11 31 | <3 25 |
| 4 | BACK WALL 6' | 45 | 0 918 | 44 | 33 | | |
| 4 | BACK WALL 6' | 44 | 0 8976 | 67 | 51 | | |
| 4 | PERSONAL | 51 | 1 01949 | | | 1766 | 508 |
| 4 | PERSONAL | 51 | 1 01949 | | | <9 81 | <2 82 |
| 4 | PERSONAL | 44 | 0 87956 | | | 2388 | 687 |
| 4 | PERSONAL | 44 | 0 87956 | | | 11 | 3 |
| 4 | PERSONAL | 51 | 1 03938 | 96 | 73 | | |
| 4 | PERSONAL | 44 | 0 89672 | 123 | 94 | | |
| 4 | GARAGE FLOOR | 41 | 0 81221 | | | 2216 | 638 |
| 4 | GARAGE FLOOR | 41 | 0 81221 | | | <12 31 | <3 54 |
| 4 | GARAGE CEILING | 41 | 0 8364 | | | 705 | 203 |
| 4 | GARAGE CEILING | 41 | 0 8364 | | | <11 96 | <3 44 |
| | | | | | | | |
| 5 | RINSE RT 5' | 59 | 1 21835 | | | 230 | 66 |
| 5 | RINSE RT 5' | 59 | 1 21835 | | | <8 21 | <2 36 |
| 5 | RINSE RT 5' | 51 | 1 05315 | | | 275 | 79 |
| 5 | RINSE RT 5' | 51 | 1 05315 | | | <9 50 | <2 73 |
| 5 | RINSE RT 5' | 58 | 1 16174 | 17 | 13 | | |

| SETUP | PERSON/ LOCATION CODE | TIME (min) | VOLUME (liters) | METHANOL (mg/m3) | METHANOL (ppm) | METHYLENE CHLORIDE (mg/m3) | METHYLENE CHLORIDE (ppm) |
|---|---|---|---|---|---|---|---|
| 5 | RINSE RT 5' | 51 | 1 02153 | 20 | 15 | | |
| 5 | FLOW RT 5' | 59 | 1 15286 | | | 208 | 60 |
| 5 | FLOW RT 5' | 59 | 1 15286 | | | <8 67 | <2 50 |
| 5 | FLOW RT 5' | 50 | 0 977 | | | 184 | 53 |
| 5 | FLOW RT 5' | 50 | 0 977 | | | <10 24 | <2 95 |
| 5 | FLOW RT 5' | 59 | 1 1977 | 8 | 6 | | |
| 5 | FLOW RT 5' | 49 | 0 9947 | <20 11 | <15 34 | | |
| 5 | BACK WALL 6' | 58 | 1 1658 | | | 103 | 30 |
| 5 | BACK WALL 6' | 58 | 1 1658 | | | <8 58 | <2 47 |
| 5 | BACK WALL 6' | 51 | 1 0251 | | | 117 | 34 |
| 5 | BACK WALL 6' | 51 | 1 0251 | | | <9 76 | <2 81 |
| 5 | BACK WALL 6' | 59 | 1 2036 | <8 31 | <6 34 | | |
| 5 | BACK WALL 6' | 51 | 1 0404 | <19 22 | <14 67 | | |
| 5 | FLOW RT B | 59 | 1 1741 | | | 230 | 66 |
| 5 | FLOW RT B | 59 | 1 1741 | | | 9 | 2 |
| 5 | FLOW RT B | 50 | 0 995 | | | 422 | 122 |
| 5 | FLOW RT B | 50 | 0 995 | | | 10 | 3 |
| 5 | FLOW RT F | 59 | 1 15522 | | | 623 | 179 |
| 5 | FLOW RT F | 59 | 1 15522 | | | <8 66 | <2 49 |
| 5 | FLOW RT F | 49 | 0 95942 | | | 740 | 213 |
| 5 | FLOW RT F | 49 | 0 95942 | | | <10 42 | <3 00 |
| 5 | FLOW LT B | 59 | 1 1505 | | | 139 | 40 |
| 5 | FLOW LT B | 59 | 1 1505 | | | <8 69 | <2 50 |
| 5 | FLOW LT B | 49 | 0 9555 | | | 167 | 48 |
| 5 | FLOW LT B | 49 | 0 9555 | | | <10 47 | <3 01 |
| 5 | FLOW LT F | 59 | 1 18118 | | | 254 | 73 |
| 5 | FLOW LT F | 59 | 1 18118 | | | <8 47 | <2 44 |
| 5 | FLOW LT F | 49 | 0 98098 | | | 285 | 82 |
| 5 | FLOW LT F | 49 | 0 98098 | | | <10 19 | <2 93 |
| 5 | PERSONAL | 55 | 1 09945 | | | 1364 | 393 |
| 5 | PERSONAL | 55 | 1 09945 | | | <9 10 | <2 62 |

| *SETUP* | *PERSON/ LOCATION CODE* | *TIME (min)* | *VOLUME (liters)* | *METHANOL (mg/m3)* | *METHANOL (ppm)* | *METHYLENE CHLORIDE (mg/m3)* | *METHYLENE CHLORIDE (ppm)* |
|---|---|---|---|---|---|---|---|
| 5 | PERSONAL | 45 | 0 8995 | | | 1223 | 352 |
| 5 | PERSONAL | 45 | 0 8995 | | | <11 12 | <3 20 |
| 5 | PERSONAL | 55 | 1 1209 | 71 | 54 | | |
| 5 | PERSONAL | 45 | 0 9171 | 76 | 58 | | |

APPENDIX B STATISTICAL METHODS

The assumption that setup by location interaction was zero was supported by the nonsignificant test of that effect (this assumption is necessary for the validity of the tests for the effects of both setup and location, respectively) Thus, the point estimates in the table for setup by location concentrations were computed by using the estimates for intercept, setup coefficients, and location coefficients from the fitted model for the log transformed data Under the simple error assumptions used, these estimators, rather than the setup by location cell means, would be the unbiased with minimum variance estimators of the concentrations by setup and location

The estimated variances for these estimators were obtained by using the model to determine the variances of the estimators and then obtaining a linear function of the "between chairs" mean square error and the "location by chairs" mean square error to unbiasedly estimate those variances The true variance of the estimator for the concentration by setup and location is a linear function of the "between chairs" variance and the "pure error" variance The "between chairs" mean square error is a function of the "between chairs" variance and the "pure error" variance, while the "location by chairs" mean square error is a function of only the "pure error" variance

The standard error of an estimated setup by location concentration was obtained as the square root of the estimated variance The degrees of freedom for the estimated standard error was approximated using Satterthwaite's approximation (see, for example, Scheffe', 1959) Since 16 intervals are estimated simultaneously, 0 025 was divided by 16 and subtracted from 1 0 for the probability level required to assure 95% simultaneous confidence using the Bonferroni approach The SAS function, TINV, was used to find the critical $t$ value corresponding to the required probability level for the approximated degrees of freedom A 95% simultaneous confidence interval was obtained by multiplying the critical $t$ value by the estimated standard error and subtracting and adding, respectively, the result from the estimated setup - location concentration

Finally, the original scale values in Table D were obtained from the log transformed values by taking the anti-log of each value and multiplying by the anti-log of the estimated standard error squared The rationale for the logarithmic transformation was to reduce heterogeneity of variances and to remove the setup by location interaction for both the methylene chloride and the methanol data, not because there was reason to believe the data was lognormally distributed, but either motivation would lead to the same procedures

The variance of a setup by location estimator of methylene chloride (for illustration) concentration is

V(setup x location est ) = [V(chairs) + 7*V(pure error)/16]/J

where V(x) - variance of the random variable x,

7 - number setups + number locations - 1,

16 = number setups * number locations, and

J = number of chairs for the setup

The expected values of the relevant mean squares are

MS(chairs) = 4 * V(chairs) + V(pure error) and

MS(location by setup) = V(pure error)

Thus, EV (setup x location est ) =

(MSE(chairs)/4 + 3*MSE(location by setup)/16)/J

where EV(x) is the estimated variance of x