ABSTRACT

JOHN J. McANENY. Volatilization of Mineral Oil Mist Collected on Sampling Filters.
(Under the direction of Dr. DAVID LEITH)

Exposure to mineral oil mist has been associated with the development of asthma, dermatitis, lipid pneumonia, and cancers of the digestive tract. The NIOSH analytical method for sampling mineral oil mists specifies oil mist collection on filters. In this study, mineral oil mist collection on glass fiber and polyvinyl chloride filters was examined to determine if significant quantities of mineral oil volatilize from filters after collection. Evaporative loss from an electrostatic precipitator was also examined. Filters were placed in an oil mist loading chamber and rapidly loaded with oil mist. The filters were removed from the chamber and weighed to determine the mass of oil loaded on the filter. After clean air was drawn through the filters for four hours, the filters were reweighed to determine the mass of oil lost to evaporation. A similar procedure was followed for the electrostatic precipitator. Fresh mineral oil on glass fiber and polyvinyl chloride filters lost approximately 35% of its original mass; used mineral oil lost approximately 12%. Evaporative losses from the electrostatic precipitator were significantly less. These findings suggest mineral oil volatilizes from polyvinyl chloride and glass fiber filters in significant quantities during the collection of an 8-hour personal sample, which would result in significant underestimation of worker exposure to oil mist.

key words: mineral oil; oil mist; PVC filters; glass fiber filters; volatilization; evaporation

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INTRODUCTION

The Ford Motor Company and the United Auto Workers have been supporting University of North Carolina research of oil mist collection devices that are used in automobile manufacturing facilities. This research has suggested mineral oil may volatilize from the filter media used in mist collection devices. The NIOSH analytical method for sampling mineral oil in the workplace to determine compliance with occupational exposure standards specifies sample collection on polyvinyl chloride, mixed cellulose ester, or glass fiber filters. Thus, the question naturally arose as to whether mineral oil may volatilize to a significant extent from filters during the collection of an 8-hour personal sample.

The work reported here shows that fresh mineral oil on glass fiber and polyvinyl chloride (PVC) filters lost approximately 35% of its original mass, while used mineral oil lost approximately 12%, due to passage of clean air through the loaded filters. This suggests mineral oil volatilizes from glass fiber and PVC filters in significant quantities during the collection of an 8-hour personal sample. Such volatilization would reduce the mass of oil on the filter and result in the underestimation of worker exposure to mineral oil mist. Electrostatic collection of these same oil mists exhibited less evaporative loss. These results need to be confirmed by a plant field study with simultaneous sampling by filters and an electrostatic precipitator.

The body of this report is being submitted as a manuscript to Applied Occupational and Environmental Hygiene. The constraints of manuscript format prevent certain information from appearing in the main text, as it would be inappropriate for a journal article. However, this information is contained in the appendices of this report. The first appendix contains experimental data, the second contains the standard operating

procedure for these experiments, the third contains statistical information, and the fourth is a discussion of the proposed field study.

BACKGROUND

Metal-working fluids can be grouped into four major categories: straight cutting oils, which are undiluted mineral and fatty oils; soluble metal-working fluids, which are water emulsions of mineral and fatty oils; synthetic metal-working fluids, which are chemical solutions of organic compounds and inorganic salts in water; and semi-synthetics, which are emulsions of mineral oil with water and the chemicals found in synthetics.⁽¹⁾ These fluids are used in metal working operations to lubricate grinding contact surfaces, to dissipate heat, and to remove ground material from the metal working contact site.⁽²⁾

Straight mineral oils are petroleum derivatives, and are distinguished from fatty oils derived from animal or vegetable sources.⁽³⁾ Extreme pressure additives such as sulfur flour and chlorinated fats can be added to mineral oils to help minimize friction and heat build-up at the cutting surface.⁽¹⁾ Application of these mineral oils to cutting surfaces results in the generation of an oil mist. Aerosolized mineral oil may contribute to the development of asthma, dermatitis, and lipid pneumonia.^(2,4)

Recent epidemiological evidence has shown significant and cumulative exposure-related associations between cancers of the digestive tract and exposure to mineral oils.^(1,2) However, the potential carcinogenicity of a mineral oil is a function of its refinement.⁽⁵⁾ Thus the ACGIH has recommended two threshold limit values for mineral oil mist in the 1993-1994 Notice of Intended Changes, with the higher value of 5 mg/m³ proposed for more severely refined oils, and the lower value of 0.2 mg/m³, and an A1 carcinogen

designation, for mildly refined oils. As over 6 million workers in the United States are exposed to mineral oils, accurate monitoring of oil mist concentrations is essential.⁽⁶⁾

The NIOSH analytical method for mineral oil mist specifies sample collection on polyvinyl chloride (PVC), mixed cellulose ester, or glass fiber filters followed by extraction of the oil with trichlorotrifluoroethane and infrared analysis.⁽⁷⁾ However, recent research by Ramachandran and Leith suggests some mineral oils may volatilize from filter media.⁽⁸⁾ They used glass fiber filters and an electrostatic precipitator to sample simultaneously from a chamber with uniform oil mist concentration and found excellent agreement between the two methods for non-volatile di-octyl phthalate. However, when sampling a mineral oil used in machining operations, concentrations determined from sampling onto glass fiber filters were substantially lower than concentrations determined using the electrostatic sampler. The authors hypothesized that this difference was due to the evaporation of collected oil from the glass fiber filter. In an evaluation of an oil mist filtration collector, Raynor also found evidence that mineral oil may evaporate from filter media by the continual passage of air through the filter, thus removing the more volatile components of the collected oil.⁽⁹⁾

If volatilization of mineral oil from a filter occurs during the collection of an 8 - hour personal sample, oil mist exposure of the worker would be underestimated. Factors that contribute to this evaporation include temperature, degree of air saturation with organic vapors, velocity of air across the filter, composition of the oil, and the size distribution of the oil mist. The purpose of this paper was to investigate the extent that mineral oil evaporates from PVC and glass fiber filters under controlled laboratory conditions. In addition, collection via electrostatic precipitation was investigated to determine if this collection method yielded a different evaporative loss.

METHODS

Gravimetric Analysis

Three types of oil were used in this study: fresh mineral oil, used mineral oil, and oleic acid. The fresh mineral oil (Metal Lubricants Co., Detroit, MI) was an unused sample of an oil used in an engine manufacturing plant, whereas the used mineral oil had been reclaimed from a sump at the engine plant. Oleic acid (Fisher Scientific, Pittsburgh, PA) was used as a check for losses with a relatively non-volatile fluid. Each oil was tested on 47mm glass fiber filters (EPM 200, Whatman International Ltd., Maidstone, England), and 47mm PVC filters with a 5 μ m pore size (Gellman Sciences, Ann Arbor, MI).

For each experiment, two experimental filters and a control filter equilibrated with room conditions for at least 1 hour.⁽¹⁰⁻¹²⁾ The filters were passed over a polonium source to remove static charges and weighed on a Cahn Model 27 electrobalance. The initial mass, as an average of three weighings, was recorded. The two experimental filters were placed in separate open-faced cassette holders (effective diameter 39mm) and introduced into the oil mist loading apparatus shown in Figure 1.

The oil mist loading apparatus was a cylindrical chamber 51cm in diameter and 137 cm tall. The six-jet Collison nebulizer (BGI Inc., Waltham, MA) and the high volume sampler were set at previously determined air pressure and flow rates to load 5mg of oil onto the filters in about seven minutes. The samples were loaded as rapidly as reasonably possible to minimize any evaporative loss during loading. The purpose of the high volume sampler was to stabilize the aerosol concentrations and to mix the air in the chamber. Five milligrams was chosen as the target mass because it represents the mass collected if a

sample were taken at 2 Lpm for 8 hours at the current ACGIH threshold limit value of $5\text{mg}/\text{m}^3$ for mineral oil mist.

After loading, the filters were removed from the chamber and immediately weighed on the Cahn microbalance to determine the mass of the loaded filter. Subtraction of the initial mass of the filter from the mass of the loaded filter yielded the mass of oil on the filter. Then the experimental filters and the control filter were placed in closed-faced filter cassettes in the experimental apparatus shown in Figure 2, where air flowed across each filter for 4 hours at 1.5 liters per minute. This flow rate represents the midpoint of the recommended flow range given in the NIOSH analytical method for mineral oil; the time period represents the average aspiration time for an 8-hour sample. After four hours each filter was reweighed three times on the microbalance and the respective mass of each filter was recorded as the average of the three weighings. Subtraction of the initial mass of the filter from this average weight yielded the mass of oil remaining after four hours. All final masses were corrected for any changes in the mass of the control filter. This procedure was performed at least twice for each oil-filter combination to obtain at least four data points for each oil-filter combination.

The gravimetric procedure used here to determine the mass of oil on a filter deviates from the NIOSH specification of solvent extraction followed by infrared spectrographic analysis. To determine the mass lost from a filter, an initial and final mass are required. Because solvent extraction removes the oil from the filter, the NIOSH extraction method could not be used to monitor the mass of oil on the same filter both before and after each test.

Electrostatic Precipitator

The oil mist loading apparatus in Figure 1 was modified to accommodate an electrostatic precipitator (MSA Co., Pittsburgh, PA). An experimental collection cylinder and control cylinder were weighed initially on a Mettler AE 200 balance. The experimental cylinder was placed in the head assembly of the precipitator and placed in the mist loading apparatus. The electrostatic precipitator ran for 30 minutes at 85 liters per minute, the precipitator's designed flow. Then the experimental cylinder was removed from the head assembly and reweighed to determine the mass at time zero. Subtraction of the initial mass of the tube from the mass at time zero yielded the mass of oil collected on the cylinder. The cylinder was returned to the head assembly and room air passed through it and a control cylinder for four hours at 85 liters per minute. After four hours, the cylinders were reweighed to determine the final mass on each tube. The mass lost was determined by the difference between the initial and final masses. Changes in the weight of the control cylinder were used to correct the final mass on the experimental cylinder.

Size Distribution

The size distribution of each oil mist was measured using an Aerosizer (Amherst Process Instruments, Inc., Hadley, MA). These measurements were made in the oil mist loading chamber under conditions approximating those of the experiments.

Vapor Pressure

The vapor pressure of the fresh and used mineral oil were measured using a McLeod gauge and vacuum pump. The vapor pressure of the oleic acid was calculated from published data.¹³

RESULTS

Figure 3 shows the percentage of oil lost from the glass fiber and PVC filters and from the electrostatic precipitator. The fresh mineral oil had an average loss of approximately 35% for the PVC and glass fiber filters, whereas the used mineral oil lost approximately 12%. The relatively non-volatile oleic acid lost only 6% of its original mass.

Figure 3 shows the oil loss for the electrostatic precipitator was about half of that for the filters that collected fresh or used mineral oil. There was no apparent difference between loss for the electrostatic precipitator and loss for both filters for oleic acid.

Analysis of variance was used to determine if the trends in Figure 3 were statistically significant. The analysis of variance requires the variance of the dependent variable in the groups being compared to be the same. This requirement was met after taking the logs of the data, which stabilized the variance in the dependent variable.

Two models were analyzed. The first model examined loss from the filters:

$$\ln (\% \text{ of oil mass lost}) = \text{oil type} + \text{filter type} + (\text{oil type} * \text{filter type}) + \text{mass originally on filter}$$

Oil type was the only significant factor in the model ($p < 0.0005$). Fresh mineral oil lost more mass than the used mineral oil ($p < 0.0005$) and oleic acid ($p < 0.0005$); used mineral oil lost more mass than oleic acid ($p = 0.004$). The mass of oil originally on the filter did not significantly affect the percentage of mass lost ($p=0.500$). Although Figure 3 suggests that more oil was lost from the PVC filters, this difference was not significant ($p=0.594$).

A second model was used to compare electrostatic and filter collection:

$$\ln (\% \text{ oil mass lost}) = \text{collector type} + \text{original mass loaded on collector}$$

Analysis of variance revealed a significant difference between electrostatic and filter collection ($p = 0.013$) for fresh mineral oil, with the electrostatic precipitator losing less oil. The same analysis for oleic acid revealed no difference between electrostatic precipitation and filter collection ($p = 0.426$).

One of the four data points for the electrostatic precipitator and used mineral oil was a negative percent removal (i.e. the cylinder weight increased slightly). Deleting this data point and using the previous model revealed a significant difference between electrostatic precipitation and filter collection ($p = 0.038$), with the electrostatic precipitator losing less oil to evaporation.

The original mass loaded was not significant for any of the oils tested, $p = 0.497$.

The size distribution for each oil mist is shown in Figure 4. The distribution for the fresh and used mineral oil match very well. Relative to the mineral oil distributions, the oleic acid distribution has fewer particles in the size ranges greater than $1.5 \mu\text{m}$, and more particles in the size ranges less than $1.5 \mu\text{m}$.

The vapor pressure of the fresh and used mineral oils was less than $100 \mu\text{m Hg}$ at 20°C . The vapor pressure of oleic acid at 20°C was calculated to be $0.006 \mu\text{m Hg}$.

DISCUSSION

Gravimetric Analysis of Filters

Mineral oil is a complex mixture of organic compounds. The shorter chain hydrocarbons in mineral oil have higher vapor pressures and thus volatilize more readily than the heavier fractions. As the lighter fractions are removed with time, the oil becomes less likely to volatilize. These trends are seen in Figure 3. The fresh mineral oil lost approximately 35% of its original mass, whereas the used mineral oil, which had probably already lost its lighter fractions to evaporation, lost significantly less mass. Pairwise comparisons confirmed that these trends were statistically significant. The continual passage of air through the filter during sampling stripped off the more volatile components of the oil, and thereby reduced the mass on the filter. These results suggest that worker exposure to mineral oil mist may be significantly underestimated when sampling mineral oil mist with glass fiber or PVC filters

Migration of mineral oil through the filters during the course of the experiments could, in principle, have distorted the results. However, the results from the experiments suggest migration was inconsequential. If losses were a function of migration through the filter and not evaporation, loss should have been just as great with the relatively non-volatile oleic acid as with the mineral oil. Figure 3 shows this was not the case. Finally, Menichini⁽¹⁰⁾ found the increased weight of back-up filters, that presumably collected migrated liquid, was always less than 1% of that of the front filters when loading up to 15mg of mineral oil on 37mm glass fiber filters. Since the target mass in these experiments was 5mg, the potential for migration through the 47mm filters should have been small.

Electrostatic Precipitator

Electrostatic collection results in the accumulation of oil droplets on the inside of a cylindrical tube. Once on the tube, the oil droplets coalesce into a film. Since the surface area of the film is much less than the aggregate surface area of all the droplets collected on a filter, less evaporative loss is expected. In addition, the saturation vapor pressure required to maintain equilibrium between the vapor and liquid is greater when the liquid surface is sharply curved than for a flat liquid surface.¹¹ Thus, the formation of a film inside the electrostatic precipitator collection cylinder, which is relatively flat compared to the surface of the small droplets collected within the filter, may further reduce evaporative loss from the electrostatic precipitator.

The results of the electrostatic precipitation experiments confirmed these expectations. The average loss of fresh mineral oil from PVC and glass fiber filters was more than that with the electrostatic precipitator ($p=0.013$); similarly, the loss of used mineral oil was more from the filters than from the precipitator ($p=0.038$). The relatively non-volatile oleic acid showed no difference between the two methods ($p=0.426$).

Small particles evaporate more readily than large particles. The size distributions of fresh and used mineral oil mist measured by the Aerosizer were almost identical. Therefore, the difference in oil mass lost between these two is not attributable to differences in the droplet size.

Figure 4 shows that oleic acid had fewer larger droplets than fresh or used mineral oil; thus, on the basis of size distribution alone, oleic acid should have been more prone to evaporation than the mineral oils. However, Figure 3 shows that less rather than more oleic acid evaporated than occurred for the mineral oils. Thus the difference in volatility

between oleic acid and the mineral oils is a stronger determinant of evaporative loss than the differences in their size distributions.

CONCLUSIONS

All the oils used in this investigation had low vapor pressures under room conditions, and so would not normally be thought to evaporate. A mist of these oils, however, has so great a surface area that aggregate evaporation from all droplets was appreciable.

Fresh mineral oil loaded as an aerosol onto glass fiber or PVC filters lost about 35% of its original mass when subjected to a flow rate of 1.5 Lpm for 4 hours. This finding suggests worker exposure to mineral oil mist measured according to the current NIOSH analytical method by collection on glass fiber or PVC filters may underestimate the true mist concentration if the mineral oil contains volatile fractions. Electrostatic collection of oil mist resulted in significantly less evaporation than filter collection.

These results need to be confirmed by a field study in a plant where oil mist is present with simultaneous sampling by filters and an electrostatic precipitator. Disparate concentration measurements between filter and electrostatic collection methods would further suggest oil volatilizes from the filters.

Factors within a plant that would affect the magnitude of evaporation include temperature, concentration of organic vapors in the air, mineral oil composition, and the size distribution of the oil mist. Increased temperature will result in higher vapor pressures and thus more evaporation, while the saturation of air with organic vapors will

decrease the amount of evaporation. In addition, the size distribution of the mineral oil mist will affect evaporation because small droplets will evaporate faster than large droplets.

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Figure 1. Oil Mist Loading Apparatus

Figure 2. Apparatus to investigate evaporation of collected oil mist

Figure 3. Percentage of oil lost from filters (PVC and glass fiber) and an electrostatic precipitator (ESP), after four hours of exposure to airflows of 1.5 Lpm and 3 cfm, respectively.

Figure 4. Frequency distribution by count for fresh mineral oil, used mineral oil, and oleic acid.

APPENDIX A

EXPERIMENTAL DATA

TABLE I: Percentage of oil lost for each oil-filter combination

GLASS FIBER FILTERS					PVC FILTERS								
oil type	% of oil lost from filter				oil type	% of oil lost from filter							
	trial	1	2	3	4		trial	1	2	3	4	5	6
fresh oil		31.5	31.3	33.6	25.7	fresh oil		36.3	42.8	42.5	36.4		
used oil		11.9	12.3	10.7	15.5	used oil		5.0	22.3	6.6	11.5	20.4	15.9
oleic acid		6.0	7.3	4.1	7.1	oleic acid		3.6	4.2	7.9	8.3		

TABLE II: Mass of oil loaded for each oil-filter test

GLASS FIBER FILTERS					PVC FILTERS								
oil type	mass of oil loaded (mg)				oil type	mass of oil loaded (mg)							
	trial	1	2	3	4		trial	1	2	3	4	5	6
fresh oil		5.28	4.99	6.41	6.24	fresh oil		6.64	6.47	4.68	4.72		
used oil		6.09	5.78	5.36	5.28	used oil		9.55	9.75	2.07	2.19	8.90	9.33
oleic acid		4.24	4.21	11.96	11.98	oleic acid		4.62	4.64	7.00	7.22		

TABLE III: *Percentage of oil lost from electrostatic precipitator*

	trials	1	2	3	4
fresh oil		6.7	32.7	21.2	16.8
used oil		0.3	-1.6	22.8	2.3
oleic acid		7.0	2.9	10.0	5.1

TABLE IV: *Mass of oil loaded onto electrostatic precipitator (mg)*

	trials	1	2	3	4
fresh oil		22.4	42.9	209.0	277.7
used oil		80.5	25.7	121.4	175.0
oleic acid		202.5	241.9	174.7	149.9

APPENDIX B

STANDARD OPERATING PROCEDURE

STANDARD OPERATING PROCEDURE

Gravimetric Analysis:

1. Calibration of the Cahn Model 27 Electrobalance

1.1 If the 50mm stirrup is to be used in position "A", then place 60mg of weight on position "C" (the tare position).

1.2 Press tare switch two times to deactivate autotare

1.3 Set the "A" range selector to the "200" setting

1.3.1 Use the coarse zero adjustment to obtain a 0.00 reading on the display

1.4 Set "A" range selector to "2" setting.

1.4.1 Use the fine zero adjustment to obtain a 0.000 reading on the display. NOTE: Should the fine zero control run out of adjustment, reset the range switch to the "200" mark, and turn the fine zero control knob a full 5 (five) turns in the opposite direction from the stop. Re-adjust the coarse zero control knob to obtain a zero reading. Switch back to the "2" setting and use the fine zero to complete the adjustment.

1.4.2 Lock both the fine and coarse adjustment knobs.

1.5 Set "A" range selector to the "200" setting.

1.5.1 Place 200mg calibration weight on stirrup A.

1.5.2 Adjust calibration knob until the display reads 199.99 and then lock the calibration knob.

1.5.3 Remove the calibration weight and check that the balance re-zeros. Calibration is complete.

2. Preparation of filters

2.1 Allow 3 47mm filters to sit in room conditions for at least 1 hour.

2.2 Designate filters 1,2 and control. Record filter type, lot number, and temperature on data sheet.

2.2.1 Using forceps, weigh filter 1 three times, each time passing over polonium source to remove any static charge, and check that balance re-zeros between weighings. Record weights on data sheet.

2.2.1.1 Place filter 1 in open faced filter holder designated "1".

2.2.2 Repeat 2.2.1 and 2.2.1.1 for filter 2.

2.2.3 Weigh control filter as in 2.2.1. Place in the designated closed faced filter holder in the experimental sampling train (Figure 1).

2.3 Secure filter cassettes 1 and 2 in the center of the mineral oil mist loading chamber (Figure 2), orient the filter faces such that they are facing the bottom of the chamber, and close the sample chamber.

2.3.1 Set the variac attached to the Hi-Vol to 18% and 120v, and turn on.

2.3.2 Turn on air flow to 6 jet collision nebulizer and set at 7.4cfh.

2.3.3 Allow the concentration in the chamber to equilibrate for 5 - 10 minutes.

2.3.4 Draw air through filters 1 and 2 for at 90cfh for seven minutes.

2.3.5 Shut down all airflows and the Hi-Vol.

2.4 Before removing cassettes 1 and 2, remove the control from its filter holder and weigh as in 2.2.3. Record data on data sheet under time = 0 hours.

2.5 Remove filter holder one and two from the chamber.

2.5.1 Weigh filter 1 and 2 as in 2.2.1 and record data on data sheet under mass at time = 0 hours.

2.5.2 Place filter 1 and 2 in designated filter holders in the experimental set up (refer to figure 1).

2.6 Draw 1.5 liters/minute across all three filters for two hours.

2.6.1 At the end of two hours remove filters from their respective holders, weigh the filters as before, record the weights on the data sheet under mass at time = 2 hours, and then replace filters in their appropriate holder in the experimental set up.

2.6.2 Continue to pass air through filter at 1.5 liters/minute for an additional two hours

2.7 At the end of the second two hours, remove the filters from their holders, weigh the filters as before, record the weights on the data sheet under mass at time = 4 hours, and then discard the filters.

STANDARD OPERATING PROCEDURE

Electrostatic Precipitator

1. Preparation of ESP cylinders

- 1.1 Wash cylinders with soap and water.
- 1.2 Rinse with isopropyl alcohol
- 1.3 Let dry overnight and cap when clean and dry
- 1.4 Handle cylinders only with kim wipes so that there is no contact between skin and the cylinders.

2. Weighing cylinders to establish initial weight.

- 2.1 With caps in place, weigh both the experimental cylinder and control cylinder on the Mettler AE 200 balance. Weigh each cylinder three times and record the weights on the data sheet as the initial mass.

3. Loading oil onto the cylinder

3.1 Sample oil under the following conditions

- 3.1.1 Flow to the six jet collision nebulizer = 7.0cfh
- 3.1.2 Voltage of ESP = 14 kV
- 3.1.3 Variac setting for Hi-Vol = 0 - 20, depending on the concentration desired.

- 3.2 Collect sample on experimental cylinder for 1/2 hour. Shut down all power and air flows. Withdraw ESP cylinder from chamber.

- 3.3 Remove cylinder from head assembly and recap.

- 3.4 Weigh cylinder as in 2.1 and record mass on data sheet.

4. Drawing air through the cylinders

- 4.1 Uncap the experimental cylinder and return to the head assembly.

- 4.2 Place the ESP assembly and the control cylinder in close proximity and draw 3cfm through both tubes for four hours.

- 4.3 At the end of four hours remove and cap both cylinders. Weigh each cylinder as in 2.1

4.4 Correct all final masses for any changes in the control mass.

Figure 1. Oil Mist Loading Apparatus

Figure 2. Apparatus to investigate evaporation of collected oil mist

OIL EXPERIMENT DATA SHEET FOR CAHN BALANCE

DATE

TEMP.

VARIAC = 18.5 AT 120

FLOW NEB = 7.4CFH

FLOW FILTER = 90CFH DURING LOADING

LET EQUILIBRATE FOR FIVE MIN THEN COLLECT FOR 7 MIN

FLOW THROUGH FILTER = 1.5LPM FOR FOUR HRS

<u>TIME</u>		<u>FILTER 1 (mg)</u>	<u>FILTER 2 (mg)</u>	<u>CONTROL (mg)</u>
preweigh	1			
	2			
	3			
0 hrs	1			
	2			
	3			
2 hrs	1			
	2			
	3			
4 hrs	1			
	2			
	3			

ESP DATA SHEET

DATE:
TEMP:
FLOW TO NEB.:
VOLTAGE OF ESP: ≈ 14 kV
TIME OF LOADING:
HI VOL: ON / OFF
SETTING:

Initial mass of tube

1

2

3

Initial mass of control

1

2

3

Loaded mass of tube

1

2

3

Final mass of tube (t = 4hrs)

1

2

3

Final mass of control (t = 4hrs)

1

2

3

APPENDIX C

STATISTICAL ANALYSIS OF DATA

FILTER DATA

The filter data were analyzed with ANOVA on SYSTAT. The data were entered in a format to account for filter experiments being run simultaneously under identical conditions. This was accomplished by averaging the results of the paired filters and entering the average as one data point.

The model used in the analysis was:

$$\ln(\% \text{ of mass lost}) = \text{oil type} + \text{filter type} + (\text{oil type} * \text{filter type}) + \text{mass originally on filter}$$

(Oil and filter type were designated as categorical variables.) SYSTAT generated the following ANOVA table:

Source	Sum of Squares	df	Mean Square	F ratio	p
oil	6.40	2	3.199	39.28	0.000
filter	0.026	1	0.026	0.318	0.594
oil*filter	0.044	2	0.022	0.269	0.773
mass	0.042	1	0.042	0.515	0.500
error	0.489	6	0.081		

The SYSTAT forward stepwise selection procedure (Alpha-to-enter = Alpha-to-remove = 0.015) produced a model with oil as the only significant factor.

These two analyses demonstrated oil type was the only significant factor when trying to estimate the percentage of oil mass lost to evaporation.

Differences between oil types were examined using the same model and limiting the data set to two oil types per analysis. The use of fresh and used mineral oil data yielded oil type as the only significant factor ($p < 0.0005$). The use of fresh mineral oil and oleic acid also yielded oil type as the only significant factor ($p < 0.0005$). Finally,

limiting the data set to used mineral oil and oleic acid yielded oil type as the only significant factor ($p = 0.004$). These analyses demonstrate fresh mineral oil will lose significantly more mass to evaporation than used mineral oil or oleic acid, and used mineral oil will lose significantly more mass to evaporation than oleic acid.

ELECTROSTATIC PRECIPITATOR DATA

The electrostatic precipitator data were analyzed with an Analysis of Variance on SYSTAT. A separate analysis was performed for each oil type because the reduction of evaporative loss within each oil type was the main concern of this experiment. The model used to analyze the data was:

$$\ln (\% \text{ oil lost}) = \text{collector type} + \text{original mass loaded on the collector}$$

The original mass loaded was not a factor for any oil. The p values for collector type were $p = 0.013$ for fresh mineral oil, $p = 0.038$ for used mineral oil, and $p = 0.426$ for oleic acid.

These analyses demonstrated electrostatic collection resulted in significantly less evaporative loss when using fresh or used mineral oil, but did not differ significantly for oleic acid.

APPENDIX D

DISCUSSION OF PROPOSED FIELD STUDY

The results of this study need to be confirmed by an actual plant field study with simultaneous sampling by filters and an electrostatic precipitator. Assuming the two methods have a similar collection efficiency, the finding of disparate concentration measurements between filter and electrostatic collection methods suggests oil volatilizing from the filters.

Several factors unique to each plant that effect evaporation were previously discussed. These include temperature, concentration of organic vapors in the air, mineral oil composition, and the size distribution of the oil mist. Additional factors that would differ between the plant and the laboratory include the effect of rapid oil loading onto the filter vs. gradual loading, filter size, open-faced vs. closed faced filter cassettes, the use of fresh vs. recycled mineral oil, and the presence of multiple contaminants. In this study mineral oil was loaded onto the filters at 90 cfh for seven minutes to minimize evaporative losses. The effect of gradually loading a filter with mineral oil at 1.5 Lpm during an 8-hour work shift would be explored in the plant study. Secondly, the NIOSH analytical method for mineral oil specifies the use of 37 mm filters to monitor worker exposure; 47mm filters were used in this study. A smaller filter operated at the same flow will have a higher velocity across the filter than the larger filter, which would tend to increase evaporative losses. However, the velocity across the 47 mm filters did fall within the acceptable ranges specified in the NIOSH method. Therefore, the main filter size issue the plant study will resolve is the effect of the smaller surface area of the 37mm filter onto which the mineral oil mass spreads. This smaller surface area may tend to decrease evaporative losses. Thirdly, although the oil mist was loaded using open-faced cassettes, the filters were subsequently transferred to the experimental set-up of Figure 2, which contained closed-faced cassettes. The proposed plant study will use only open-faced filter cassettes. This difference will affect the air flow characteristics through the filter and, consequently, could affect the degree of evaporation.

Fourthly, some plants use only fresh mineral oil while others filter, refreshen, and reuse this coolant. The plant that uses only fresh material runs the greater risk of underestimating worker exposure when sampling on PVC and glass fiber filters, because air flow through the filters will cause the shorter chain hydrocarbons to volatilize and further contaminate the plant air. In plants where recycled mineral oil is used, these lighter components have evaporated previously, and hence less evaporative loss is expected.

Finally, this study examined fresh and used mineral oils separately, whereas in actual plant conditions other types of oils and chemicals may also be present. The existence of synthetic fluids, soluble oils, and other plant contaminants may further influence the results.