ANALYTICAL SCIENCE & TECHNOLOGY
Vol.14, No.5, 451-457, 2001
Printed in the Republic of Korea

Loss of Metalworking Fluids Collected on PVC Filter Due to Contact with Clean Air and Desiccation

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(Received , 2001, Sep. 11)

PVC필터에 채취된 절삭유의 손실에 관한 연구

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(2001. 9. 11. 접수)

Abstract : Because liquids with high molecular weight such as mineral oil have low vapor pressure at room temperature, it is generally thought to be difficult to lose them to evaporation. However, when they are dispersed into air in small droplets during application in machining processes, their surface area becomes considerably higher. To determine the potential for metalworking fluids (MWF) filter losses, MWF mist was generated and collected on polyvinyl chloride (PVC) filters in test chamber. After collected MWF was exposed to clean air during designated period (range 10~240 minutes) and the filters were desiccated, losses were evaluated. As duration of clean air passing through PVC filter increased, loss of MWF gradually increased. MWF lost after 10 minutes ranged from 12.4 % to 21.8 % of the original loading mass, on average 53.3 % of the total loss. These results indicate that significant mass of MWF collected on PVC filters can be lost at the beginning of air sampling. Loss of MWF collected on PVC filter also occurred during filter desiccation without active airflow. In multiple regression to identify which factors influence the loss of MWF collected on PVC filter, both duration of air passing through PVC filter and MWF age (fresh vs. used) were significant predictor (p=0.0001). Therefore, workers' exposure to MWF measured according to filter methods such as National Institute for Occupational Safety and Health (NIOSH), method 0500, may underestimate true concentration. Further study is needed to develop a new method to quantify the workers' exposure to airborne MWF mist accurately.

요 약 : 절삭유(Metalworking Fludis, MWF) 노출로 인한 건강상의 장애는 암, 호흡기질환, 피부질환이다. MWF는 20여가지 이상의 화학물질이 혼합된 고분자의 화합물로서 상온에서 쉽게 증발되지 않는다. 이러한 특성으로 공기 중 MWF미스트의 측정과 분석은 PVC필터를 이용한 중량법이 국제적으로 공인되어 이용되고 있다. 그러나 사업장에서 MWF는 사용과정에서 분산되면 표면적

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이 커지고 증발하기 쉬운 상태로 된다. 본 연구는 실험실에 MWF미스트 발생장치를 제작하여 MWF미스트가 필터에 채취되고 분석되는 과정에서 손실되는 양과 원인을 정량적으로 분석하였다. 즉 챔버에서 MWF가 채취된 PVC필터를 깨끗한 공기로 일정시간동안(10 ~ 240 분) 접촉하고 건조하여 각각의 과정(공기접촉, 건조기간)에서의 손실을 평가하였다. 공기와의 접촉 10분 후에 손실된 MWF양은 원래양의 12.4 % - 21.8 %였다. 전과정에서 손실된 양의 53.3 %가 공기의 접촉 초기에 일어나는 것을 확인하였다. PVC필터에 채취된 MWF의 손실은 건조과정에서 일어난 것을 확인하였다. PVC필터에 채취된 MWF의 손실에 영향을 미치는 요인을 분석하기 위한 다중회귀분석에서 MWF의 특성(사용중인 것과 사용하지 않은 것)이 유의한 예측변수였다. 이 연구 결과에 따르면, 국제적으로 공인된 중량법에 의한 공기중 MWF측정은 과소평가되는 것으로 판단된다.

Key words : Metalworking fluids(MWF), MWF mist

1. Introduction

Metalworking Fluids (MWFs) are fluids used during machining and grinding to prolong the life of the tool, carry away debris, and protect the surfaces of the work pieces. Workers exposed to MWF have developed skin disorders (irritation, rashes, oil acne) and respiratory symptoms or disorders (breathing problems, cough, chest tightness, asthma).[1-2] Recent epidemiological evidence indicates that exposure to MWF is significantly associated with increased risk of larynx, rectum, pancreas, skin, scrotum and bladder cancers.[1,3-4] The Occupational Safety and Health Administration (OSHA) identifies MWF as one of the top 18 health and safety priorities and has conducted risk assessment for MWF.[5]

To assess the risk caused by MWF, it is most important to measure workes' exposure accurately. Current National Institute for Occupational Safety and Health (NIOSH) analytical method, 0500, as well as American Society for Testing and Materials (ASTM), PS42-97, recommends aerosol filtration for gravimetric analysis. According to these methods, polyvinyl chloride (PVC) or glass fiber (GF) filters can be used to collect airborne mineral oil mist.[6-7]

These methods of collecting airborne aerosols rely on the assumption that aerosols collected on the filters are not lost. Several studies have examined filtration methods for collecting airborne mineral oil. Mcaneny et al. (1995) concluded that the percentage of loss was 35 % of the original mass of fresh mineral oil and 12 % of used mineral oil.[8] Volckens et al. (1997) found that mineral oil collected on GF, polytetrafluoro ethylene (PTFE), and PVC might evaporate during sampling.[9] Both studies reached similar conclusion that mineral oil mist collected on a filter might be lost to evaporation during sampling. Both of these results were obtained from experiments where air passed through a filter for either 4 or 8 hours. If volatilization of mineral oil mist from a filter occurs, workers' exposure to mineral oil would be underestimated.

The purpose of this study was to examine whether the loss of MWF mist collected on PVC filters occurs not only through the passing of clean air, but also through the filter desiccation that follows air sampling. We examined four types of MWF, and determined which factors most significantly affects the loss of MWF collected on PVC filter.

2. Materials and Methods

2.1 Experimental setup and procedure

Four types of MWF tested in this pilot study were straight MWF: 3401 fresh, 3401 used, 570L fresh, 570L used. The fresh MWFs had never been used prior to the test and were obtained from the Howton MWF manufacturing company in Korea. Used MWFs were collected from a sump at Sam-Sung electronic plant in Korea. According to material safety data sheets (MSDS), the product name of 3401 was CINDOL 3401VN, a lubricant oil that has viscosity of 12 cSt at 40℃, and is composed of about 95% refined mineral oil and a few additives. The product name of 570L was CUTMAX 570L that has viscosity of 32 cSt at 40℃ and contains mineral oil (55-65%) and chlorinated paraffins (35-40%) including sulfur and chlorine to improve performance under high temperature and pressure.

The chamber used to generate the MWF mist was square (500 mm x 500 mm) and consisted of a nebulizer, a chamber cap, a beaker containing MWF and a compressor.

A personal pump to collect the MWF mist was placed outside the test chamber (*Fig.* 1).

The procedure to evaluate MWF mass lost during passing of clean air through PVC filter and further desiccation is described in *Fig.* 2.

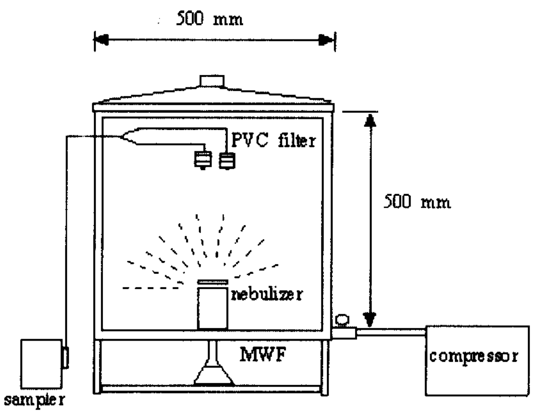

Fig. 1. MWF loading apparatus.

Desiccation

⇓

Pre-weighing - Weight of PVC filter itself

⇓

Collection of MWF mist in test chamber - Collection of airborne MWF mist using personal pump

⇓

Post-weighing 1 - MWF mist collected on PVC filter

⇓

Passage of clean air through PVC filter in a clean chamber

⇓

Post-weighing 2 - Mass of MWF after clean air passes through PVC filter for 10, 30, 60, 120 and 240 minutes

⇓

Desiccation

⇓

Post-weighing 3 - Mass of MWF after desiccation

Fig. 2. Experimental procedure.

2.2 Collection and loading of MWF in test chamber

A bundle of 3 replicate three-piece cassettes assembled with the PVC filter (37 mm diameter, 5㎛ pore size, cat no.: P/N 225-8-01, SKC Inc.) was hung at the top of test chamber. MWF in the beaker was introduced into nebulizer and then dispersed into test chamber with 20 psi of compressed air. When the concentration of the MWF dispersed into air was high enough for effective testing, the compressor was turned off. Airborne MWF mist was collected on PVC filters using personal pump (P/N 800508-111, GilAir-3RC, Cloak) with calibrated flow rate of 2 Lpm for 5 seconds. The masses of MWF initially collected ranged from 0.50 mg to 3.13 mg (*Table 1*), and were similar for all the MWFs tested except the used 570L. PVC filters were weighed using a semi-micro electrobalance (Model ANALYTICAL, accuracy : 10^{-5} g) in area where physical environment was constantly controlled (temperature : 23.5±3℃, relative humidity : 50±15%). In addition to it, all final MWF masses were adjusted to reflect any changes caused by moisture variation and contamination in the mass of one blank filter per three filter samples.

Table 1. Mass range of MWF collected on PVC Filter

MWF type	Sample no.[A]	Mass range, mg
3401 fresh	15	1.23 - 2.56
3401 used	15	1.15 - 2.26
570L fresh	15	1.03 - 3.13
570L used	15	0.50 - 1.08
Total	60	0.50 - 3.13

[A] : Total 60 samples were tested : 4 (MWF type) x 5 (duration of air passage) x 3 replicate samples

2.3 Evaluation for loss of MWF collected on the PVC filter

The PVC filters loaded with MWF mist was weighed, re-assembled in 3-piece cassettes and placed in a clean chamber that contained 2 stages of high efficiency particulate air (HEPA) filters and activated carbon (DVB 912, The Daeil Engineering, Korea). After being drawn through the HEPA filter and activated carbon, clean air passed through the PVC filters loaded with MWF mist using a personal pump that was calibrated to approximately 2 Lpm for 10, 30, 60, 120, and 240 minutes, respectively. Three replicate filters were tested for each duration and MWF type. After clean air was passed through a PVC filter for the designated period of time, it was removed and re-weighed immediately. Subtraction of the mass of the PVC filter after clean air passage from the mass of the loaded PVC filter yielded the mass of MWF lost due to contact with passing air (A).

After PVC filters were re-weighed, they were immediately desiccated for one day. Subtraction of the mass of PVC filter after desiccation from the mass of PVC filter after clean air passage yielded the mass of the MWF lost during desiccation (B).

MWF mass lost during the passage of clean air (A) and desiccation (B) was assumed to be total loss of MWF (C). All losses were expressed as percentage of initial MWF mass collected on PVC filter.

2.4 Statistical analysis

Statistical testing was carried out using SPSS standard version. Student's t test was tested to compare mean loss by MWF age (fresh vs. used). To find factors that cause the loss of MWF collected on PVC filter, multiple regression was also used with original loading mass, air passage duration, MWF age and MWF product type as independent variables. Both MWF age (fresh vs. used MWF) and MWF product (570L vs. 3401) were coded as dummy variables.

3. Results

The average total loss of MWF during the passage of clean air through the PVC filter and desiccation is shown in *Table 2* and *Fig. 3.* As the duration of clean air passage through PVC filter increased, the loss of MWF collected on the PVC filter gradually increased. After 10 minutes of clean air passage through the filter, the average loss was 21.8 % of original loading mass in the 570L fresh MWF, 17.8 % in the 3401 used MWF, 15.7 % in the 570 L used MWF, and 12.4 % in the 3401 fresh MWF. These losses, presumably due to evaporation of the MWF collected on PVC filter, were proportionately greater than losses lost in longer clean air passage time periods. An average of 53.3 % of total loss took place in the first 10 minutes of air passing through PVC filter.

The loss of MWF increased gradually, until clean air passage of 60 minutes duration, and showed a flatter increase pattern after that. The average total loss of MWF mist lost after 240 minutes of clean air passing

Table 2. Average of loss of mwf collected on pvc filter depending on mwf age, duration of air passage and desiccation (%)

Duration of air passage (min)	3401 fresh			3401 used			570L fresh			570L used		
	A	B	C	A	B	C	A	B	C	A	B	C
10	9.2	3.2	12.4	13.9	3.9	17.8	14.4	7.4	21.8	7.6	8.1	15.7
30	21.2	3.7	24.9	15.7	2.4	18.1	19.9	5.7	25.6	11.2	2.7	13.9
60	23.4	3.2	26.6	17.8	3.5	21.3	20.3	5.8	26.1	12.6	4.5	17.1
120	26.8	1.3	28.1	23.9	2.1	26.0	27.3	5.1	32.4	23.9	2.0	25.9
240	29.7	0.7	30.4	24.1	3.6	27.7	33.9	3.6	37.5	26.0	4.9	30.9

A : average loss of MWF due to clean air passing through PVC filter
B : average loss of MWF during desiccation
C : average total loss of MWF collected on PVC filter
Total 60 samples were tested : 4 (MWF type) x 5 (duration of air passage) x 3 replicate samples

through the PVC filter ranged from 27.7 % to 30.9 %.

The MWF mist collected on PVC filter was lost by not only through passage of clean air, but also through desiccation. The average percentage of MWF mist lost during desiccation is compared with losses by air passage (*Table* 2 and *Fig.* 4).

It ranged from 0.7 % to 8.1 % of initial loading mass. These losses were lower than those due to clean air passing through the PVC filter. But it should be pointed out that MWF mist collected on PVC filters was lost during desiccation of all air passage times and MWF age.

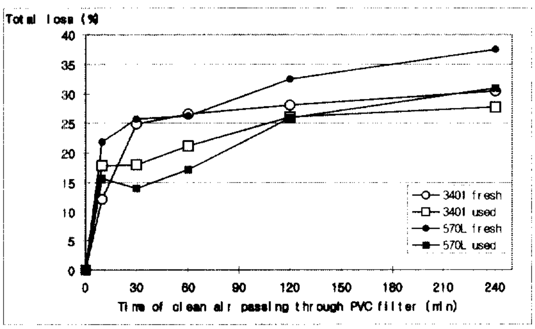

Fig. 3. Variation of MWF loss by passage time of clean air through PVC filter (%).

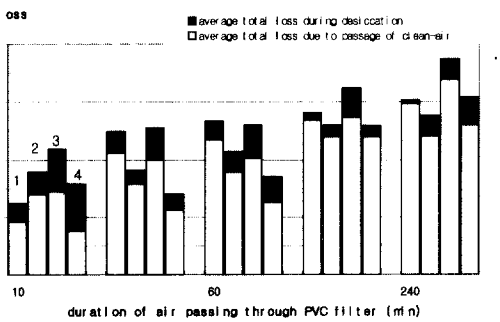

Fig. 4. Comparison of total loss by time of clean air passage through PVC filter and desiccation (1. 3401 fresh, 2. 3401 used, 3. 570L fresh, 4. 570L used).

The range of MWF losses by MWF age was 12.4-30.4 % in the 3401 fresh MWF, 17.8-27.7 % in the 3401 used MWF, 21.8-37.5 % in the 570L fresh MWF, and 13.9-30.9 % in the 570L used MWF. The losses of fresh MWF tended to be greater than those of used MWF. At clean air passage times shorter than 120 minutes, the range of the loss was 12.4-26.6 % in both fresh MWFs and 13.9-21.3% in both used MWFs (*Table* 2).

Table 3. Multiple regression model for predicting loss of MWF collected on PVC filter*

Predictor	Coefficient(β)	Standard error	Significance(p)
Constant	15.98	1.03	0.0001
Duration of passing time	0.06	0.007	0.0001
MWF age(fresh)^A	5.61	1.15	0.0001

* Multiple regression model : Dependent variable = (loss of MWF collected PVC filter, %) = 15.98 + 0.06 x (duration of passing time, min) + 5.61 (fresh MWF)(n=60, adjusted R^2 =0.628, p=0.0001)

^{A} : MWF Age (fresh vs. used MWF) was tested as dummy variable (1 if fresh MWF was tested, 0 if not) MWF product type (570L vs. 3401) and original loading mass were not significant predictors of MWF loss (p>0.05)

Table 3 shows the results of multiple regression analyzed to determine which factors significantly affect the loss of MWF collected on PVC filter. Increased duration of air passage increased filter losses, and fresh MWFs had higher losses than used MWFs. But, original loading mass and MWF product did not affect the loss of MWF collected on PVC filter.

4. Discussion

MWF may contain hundreds of components that have different chemical and physical properties.[10] Because MWFs with long carbon chains have low vapor pressure, it seems to be generally accepted that MWF does not normally evaporate at room temperature. However, when MWFs are applied at machining processes, airborne MWF mist of different sizes can be generated by splashing MWF on the workpiece and by mechanical action of machining tools. MWF mist collected on the filter may be more susceptible to evaporation than normal state as a bulk liquid at room temperature.

The assumption that MWF mist collected on the filter was lost has been confirmed by several studies. Volckens et al.(1997) had found a substantial evaporation of mineral oil after air passed through several filter media (PVC, ESP, GF) for both 4 and 8 hours.

Leith et al. (1996) found that evaporative losses from loaded MCE and PVC filters during exposure to clean air were more substantial than the losses from a loaded electrostatic precipitator (ESP) substrate.[11]

Mcaneny et al. (1995) reported that fresh mineral oil mist loaded on PVC and GF filters after 240 minutes of air passing through the filter had an average loss of approximately 35 %.[8] This result is similar to our findings that 30.4 % to 37.5 % of fresh mineral oil originally collected was lost during 240 minutes of air passage (*Table* 2). The average loss of used MWF after air passage of 240 minutes (27.7 % to 30.9 %) was considerably greater than loss reported by Mcaneny et al. (1995), approximately 12 % of original loading mass.[8] The period of prior usage, the size of MWF mist collected, and the characteristics of MWF tested may have contributed to this difference. Because used MWF already lost some of lighter components in machining process prior to collection for this study, the MWF left becomes less likely to volatilize. Pair-wise comparison found that the fresh MWF lost significantly more mass than that of used MWF ($p=0.008$). This finding was confirmed in the coefficient on the fresh MWF in multiple regression model (*Table* 3).

MWF lost after clean air passage of 10 minutes was on average 53.3 % of the total loss. These results indicate that a significant mass of MWF begins to evaporate as soon as MWF is collected on the PVC filter. Thus, loss of MWF is likely to occur from the beginning of air sampling in the field. As clean air continues to pass through PVC filter, it causes the more volatile components of collected MWF to evaporate.

The loss of MWF mist collected on PVC filters occurred during desiccation without active airflow of clean air across PVC filter. Although these losses were considerably lower than those due to the air passing through PVC filter, this result suggests that MWF mist collected on PVC filter could be evaporated during shipment, storage and desiccation as well as during air passage through PVC filters. Until now, the loss of MWF in desiccation has not been reported. It is not possible to identify specific factors that caused evaporation during desiccation in this study.

The time of air passage through PVC filter may have had an important effect on the loss of MWF collected on PVC filter. In multiple regression analysis, 46.7 % of variation in MWF loss was found to be due to duration of air passage. The effect of air passage duration on the loss of mineral oil collected on filter has not been reported. Continuing passage of air through PVC filters during sampling can cause evaporation of more volatile fractions and result in underestimation of worker' exposure.

Another factor influencing the loss of MWF was MWF age. Thus, the loss of MWF collected on filter may be influenced depending on whether the MWF is fresh or used. However, mass of MWF collected on PVC filter did not significantly affect the loss of MWF (*Table* 3). These findings are similar to those of Mcaneny et al. (1995),[8] that only MWF type (age) was significant and the mass of oil originally on the filter was insignificant for influencing the loss of mineral oil collected on the filter using analysis of variance.

5. Conclusion

This study shows that the loss of MWF mist collected on PVC filters occurred not only due to passage of clean air through the filter, but also through desiccation. The loss of MWF collected on PVC filters after 10 minutes of air passage ranged from 12.4 % to 21.8 % of initial loading mass and was proportionately greater than losses measured during the other passage times. This suggests that significant oil mass might begin to evaporate from beginning of sampling in the field. During desiccation, MWF loss ranged from 0.7 %

to 8.1 % of initial loading mass. This result suggests that the MWF mist collected on the PVC filter could be lost to evaporation at room conditions such as shipment, storage, and desiccation of a filter sampled.

Multiple regression found that the duration of air passing through PVC filter and MWF age did significantly affect on MWF loss (p=0.000). The continual passage of air through PVC filter during sampling can cause loss of MWF collected on PVC filter.

This study suggests that gravimetric methods relying on air filtration, such as NIOSH analytical method for MWF mist, could underestimate worker' true exposure. Therefore, further study is needed to develop methods that can capture and retain MWF mist throughout the sampling period, as well as during post-sampling activities.

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