Exposures to Metalworking Fluids in Small-Size Machine Shops—A Study in Progress

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ABSTRACT

The National Institute for Occupational Safety and Health (NIOSH) is conducting an industrial hygiene survey of 60 small-business machining shops using metalworking fluids (MWFs) to assess the range of worker exposures associated with a variety of existing engineering controls. Shops are being selected for study that represent a range of sizes, machining operations, machine age, fluid types, and engineering controls. Field visits are being conducted between January and October 1997 and last up to 2 days per facility. Full-shift personal and area samples for inhalable and thoracic particulates are being collected and analyzed for the "total mass" and the "MWF mass" concentrations. This paper includes preliminary results only for the personal samples collected during the initial 28 field visits. These results indicate that 92% of all total mass concentrations are below 1.0 mg/m^3. Differences were observed in the total and MWF mass concentrations by operation type and by fluid type. In general, the highest inhalable particulate mass concentrations (for both the total and MWF mass fractions) were associated with straight fluids. Grinding operations were associated with the highest average total mass concentrations, while turning operations had the highest MWF mass concentrations. For most samples collected, the "MWF mass" contribution was about 50% of the "total mass."

INTRODUCTION

Metal working fluids (MWFs) is a generic term used to cover machining fluids and cutting oils that are used for cooling, flushing, and lubricating machine tools and metal parts during machining operations such as drilling, grinding, turning, and milling. MWFs are generally grouped into four major categories: straight (undiluted mineral/fatty oils); soluble (water emulsions of mineral/fatty oils); synthetic (chemical solutions of organic compounds in water); and semi-synthetic (emulsions of mineral oil with water and the chemicals found in synthetics). An estimated 1.2 million workers in the United States are potentially exposed to MWFs. Occupational exposures may be affected by several factors, such as: fluid type; machining operation, including tool type and speed; fluid application method; engineering controls, including machine enclosures and local exhaust ventilation systems; and maintenance.

The Occupational Safety and Health Administration (OSHA) has recently established a Standards Advisory Committee to consider the need to regulate occupational exposures to MWFs. To assist the Committee in its deliberations, OSHA is collecting data on the extent of current exposures to MWFs, the engineering controls in use, the number of facilities engaged in metalworking, and the number of workers potentially exposed to MWFs. Because of the paucity of information about the extent of exposures to MWFs or existing control technology in small- to moderate-size (i.e., companies with fewer than 500 employees) machining shops, OSHA and NIOSH initiated an interagency agreement in 1996 to characterize MWF exposures in small businesses. NIOSH has primary responsibility for providing scientific oversight of all project activities. In addition to addressing OSHA's regulatory needs, this project will help determine industry-wide needs for future evaluation and control of MWF exposures.

All field investigations are being conducted by personnel from Battelle Centers of Public Health Research and Evaluation and Prezant Associates, Inc. Industrial hygienists are conducting two-day site visits to a total of 60 facilities in six cities (Seattle, Portland, Los Angeles, Cincinnati, Indianapolis, and Chicago). (There are tentative plans to include 20 additional facilities in the northeastern states later in 1997). Field studies began in January 1997 and are scheduled until October 1997. This paper presents the preliminary results of 28 surveys completed through June, 1997.

The focus of the study is on establishments in the 2-digit Standard Industrial Classification (SIC) codes 34 (fabricated metal parts), 35 (industrial and commercial machinery), 36 (electronic and other electrical equipment), and 37 (transportation equipment), which together account for 98 percent of all metal removal machines in the United States. OSHA exposure data collected between 1984-94 is also useful for identifying those SICs with establishments that have frequently demonstrated high exposure levels to mineral oil mists in the past. Facilities and workers selected for sampling are designed to represent the different machining processes/jobs, fluid types, and engineering controls commonly found in small machine shops using MWFs. The selection of facilities and workers is specifically designed to provide information about both the best and the worst exposure conditions in small-business machining industries.

METHODS

The methods described below are intended to meet the following study objectives: 1) To estimate full-shift "inhalable" particulate exposures to MWFs during metal removing operations in facilities with fewer than 500 employees; 2) To compare alternative sampling methods for estimating full-shift exposures to inhalable, thoracic, and respirable particulate; 3) To determine exposure levels associated with the engineering control techniques currently utilized; and 4) To profile machine MWF emissions over short-term periods on a real-time basis.

Personal Sampling

Full-shift *"inhalable particulate"* personal breathing zone samples are being collected for each machine operator, up to a total of 20 workers per facility. For facilities with over 20 machinists, workers are selected that provide general representation of the metal working processes, engineering controls, and fluid types used at the facility. Where several workers have the same exposure variables, the worker(s) estimated to have the highest potential exposure is selected to determine the "worst case." Likewise, wherever engineering controls (e.g., local exhaust ventilation, machine enclosures, splash guards) are present, personal samples are taken which may be used to estimate the lowest (or "best") exposure conditions and also to evaluate the effectiveness of controls. Each participating worker wore an air sampling device(s) on his/her collar during the work shift on the second day of the site visit.

Inhalable Particulate Method. Samples for inhalable particulate are being collected using tared Teflon filters (37mm diameter; 2 m pore size) in 2-piece closed-face polystyrene filter cassettes at a flow rate of 2.0 liters per minute (LPM). This method has also been referred to as a "total" particulate method, as described by NIOSH.[1] These samples are analyzed for both "total" and "extractable" mass in accordance with a provisional method for metal removal fluid aerosol developed by NIOSH and the American Society for Testing and Materials (ASTM).[2] This method is intended to differentiate the MWF-specific components of the collected particulate from the non-MWF fraction (including metals and "background" particulates).

Thoracic Particulate Methods. Previous studies have suggested that the health effects associated with exposures to MWFs are related to the size of the airborne particulate. Therefore, in addition to sampling for total particulate as described above, limited sampling is also being conducted to characterize particulate by size categories, particularly the "thoracic" fraction. Two different methods are being used to collect the thoracic particulate fraction of the MWF aerosol.

1) Thoracic Cyclone. Up to five samples per site are collected using a thoracic cyclone pre-separator (Model GK2-69, BGI Incorporated) with a tared Teflon filter (37mm diameter; 2 m pore size) in 3-piece open-face polystyrene filter cassettes at a flow rate of 1.8 LPM. These samples are analyzed for both total and extractable mass as described above.

2) Cascade Impactor. Up to five samples using a Marple personal cascade impactor (Graseby Andersen Model 292) are collected in each facility. A two-stage configuration is being used (cut points = 9.8 m and 3.5 m) so that the inhalable, thoracic, and respirable size mass fractions can be determined from a single sampler. The impactor is operated at a flow rate of 2.0 LPM; particulate is collected onto Mylar (stages 1 and 2) or polyvinyl chloride (final stage) filters. Each filter stage is analyzed gravimetrically to determine particulate mass.

For each of these two size-selective sampling methods, up to four personal full-shift samples are collected on workers who are also wearing a total particulate cassette sample. Workers are selected to wear side-by-side samples based on processes and engineering controls present in each facility.

At least one area full-shift sample for each of these methods is also collected for a side-by-side comparison of different sampling methods (see below).

Area Sampling

Full-shift *"inhalable particulate"* area ("fixed-location") samples are collected in each facility to characterize levels of MWFs associated with specific process areas. At least one sample is collected in each of the primary process areas (e.g., grinding, drilling, turning, and milling), if present. Another area away from the machining processes is sampled to determine background particulate levels in the facility.

In one process area, a side-by-side comparison of different sampling methods is performed. One sampler for each of the above methods (i.e., inhalable cassette, thoracic cyclone, and cascade impactor) is grouped together in the selected area for direct comparison of these methods. In addition, a personal electrostatic precipitator (ESP) is being used to help determine the amount of MWF aerosol that may be volatilized during normal sample collection. This method is designed to minimize evaporation of collected aerosol.[3] ESP samples are collected onto tared aluminum filters at 2 LPM; samples are then analyzed gravimetrically for total mass.

Real-Time Monitoring

Real-time particle size and gravimetric measurements are being collected using a direct-reading instrument (GRIMM Dust Monitor Model #1.105, Pioneer Emissions Detection and Control, Inc.) to characterize the particle size of the machine oil mist emissions and control effectiveness. This instrument operates on the principle of light scattering and provides particle size distributions and concentrations (including respirable, thoracic, and inhalable fractions). Real-time output is updated every six seconds and data is stored as mass units (e.g., mg/m^3) or unit concentrations (e.g., $particles/m^3$).

Observational/Environmental Data

Company managers and employees are being interviewed at each survey site to obtain information concerning process operations (e.g., types of machines, MWFs, metals, and products) and engineering controls (e.g., types of enclosures and ventilation methods/rates). Temperature and relative humidity measurements are taken both indoors and outdoors. Work activities and the use of personal protective equipment are also recorded for each worker sampled.

Bulk Fluid Samples

A bulk sample of all MWFs being used at each survey site is collected. Each fluid sample is analyzed to determine its solubility using the ASTM method. An aliquot of each bulk sample is also analyzed for limited microbial assays.

Statistical Analyses

Sample data were analyzed using the Statistical Analysis System (SAS).[4] A logarithmic transformation was used to correct skewness in the distribution. Thus, all statistical analyses were performed on the logarithmically transformed mass concentration values. Differences between fluid types and operation types were analyzed using Analysis of Variance (ANOVA).

RESULTS

Study Sites

A total of 28 machining shops have been surveyed through June 1997. These shops represent 12 different 4-digit SIC codes; businesses in codes 3728 (aircraft parts) and 3451 (screw machine products) have been surveyed most frequently (6 times each). The number of total employees and machinists per facility has ranged from 4-850 and 4-98, respectively. A total of 343 workers have been sampled to date. The majority of these workers were involved with turning (n=140) and milling (n=104) operations. An engineering control (full/partial machine enclosure or local exhaust ventilation) was used in 84% of the operations sampled.

Air samples

Only the sampling results for the personal *"inhalable particulate - cassette"* (n=336 samples) and *"thoracic particulate - cyclone"* (n=78 samples) methods are presented in this paper. These results include both the total and extractable (i.e., MWF fraction) mass concentrations.

Sampling results indicate that 92% of the inhalable particulate samples had a total mass concentration less than 1.0 mg/m^3; 70% were less than 0.5 mg/m^3(see Table 1). For the inhalable MWF mass concentrations, 97% and 86% were less than 1.0 mg/m^3 and 0.5 mg/m^3, respectively.

Table 1. Distribution of total and MWF mass concentration (mg/m^3) samples.

	Percent less than				
	5.0 mg/m^3	1.0 mg/m^3	0.5 mg/m^3	0.4 mg/m	0.2 mg/m^3
Inhalable					
Total mass	99.7	91.6	69.9	56.6	15.9
MWF mass	100	96.5	86.1	80.6	50.4
Thoracic					
Total	100	97.6	93.9	84.1	41.5
MWF mass	100	100	98.8	92.7	64.6

The personal inhalable particulate total and extractable mass concentrations by type of metalworking fluid are presented in Tables 2 and 3, respectively. Results are presented in rank order of geometric mean (GM) since data were tested to be lognormally distributed. In general, the highest mass concentrations were associated with straight fluids, while the lowest were measured for synthetic fluids; the mass concentration for straight fluids was significantly higher ($p<0.05$) than all other fluid types. On average, about 50% of the total mass concentration was attributable to the MWF fraction; samples involving straight fluids had a slightly higher average MWF fraction (66%) than measured for the other fluid types. The inhalable particulate total and extractable mass concentrations by type of machining operation are shown in Tables 4 and 5, respectively. The average mass concentrations varied somewhat by operation type. Those workers performing grinding operations had the highest average total mass concentration (0.79 mg/m^3); the highest average MWF mass concentration was measured for turning operations (0.38 mg/m^3). The average background (i.e., as measured in areas separate from the machining areas) total mass concentration in the study facilities (n=9 samples) was 0.10 mg/m^3.

Table 2. Results of personal inhalable particulate "total" mass concentration (mg/m^3) samples by type of metalworking fluid.

Fluid Type	N	Mean	SD	GM	GSD	Min-Max
Straight oil	104	0.72	1.10	0.50	2.08	0.10-10.4
Soluble oil	87	0.47	0.39	0.37	1.89	0.06-2.41
Semi-synthetic	84	0.44	0.47	0.32	2.14	0.05-3.19
None (Dry)	25	0.35	0.32	0.29	1.96	0.00-1.64
Synthetic	37	0.33	0.20	0.29	1.65	0.12-1.14
Water	1	0.26	-	0.26	-	-

Table 3. Results of personal inhalable particulate "extractable" mass concentration (mg/m^3) samples by type of metalworking fluid.

Fluid Type	N	Mean	SD	GM	GSD	Min-Max
Straight oil	103	0.48	0.49	0.34	2.25	0.05-3.05
Water	1	0.19	-	0.19	-	-
Soluble oil	86	0.27	0.35	0.19	2.16	0.04-2.26
Semi-synthetic	84	0.22	0.18	0.17	2.15	0.02-0.81
None (Dry)	24	0.17	0.12	0.15	1.90	0.00-0.54
Synthetic	37	0.16	0.13	0.12	2.26	0.02-0.51

Table 4. Results of personal inhalable particulate "total" mass concentration (mg/m^3) samples by type of machining operation.

Fluid Type	N	Mean	SD	GM	GSD	Min-Max
Grinding	41	0.79	1.61	0.45	2.37	0.14-10.4
Turning	140	0.54	0.53	0.41	1.98	0.06-3.26
Other	24	0.49	0.40	0.39	2.00	0.09-1.64
Drilling	13	0.38	0.32	0.34	1.87	0.00-1.31
Milling	107	0.39	0.32	0.31	1.92	0.05-2.67

Table 5. Results of personal inhalable particulate "extractable" mass concentration (mg/m^3) samples by type of machining operation.

Fluid Type	N	Mean	SD	GM	GSD	Min-Max
Turning	139	0.38	0.43	0.27	2.29	0.02-3.05
Grinding	41	0.37	0.46	0.22	2.79	0.02-2.26
Other	23	0.27	0.24	0.22	2.07	0.00-1.13
Drilling	12	0.17	0.12	0.16	1.82	0.00-0.43
Milling	107	0.19	0.12	0.15	1.99	0.03-0.67

SUMMARY

Preliminary results from an on-going survey of small-size machine shops indicate differences in total and extractable mass concentrations by operation type and by fluid type. The highest mass concentrations were associated with straight fluids and with grinding and turning operations. The majority of inhalable particulate samples had total mass concentrations (70%) and extractable mass concentrations (86%) were below 0.5 mg/m^3. Additional results will be reported at the completion of all field surveys.

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The reader will notice a variety of nomenclature differences among authors when referring to these fluids which were the subject of the Symposium and of this volume. Indeed, even the Symposium title reflected some of this variation: "*Metalworking* Fluids Symposium II," and "The Industrial Metalworking Environment: Assessment and Control of *Metal Removal* Fluids." Lest we add to the confusion, our use of the term *metalworking* in the title "Metalworking Fluids Symposium II" was a conscious decision based on nothing more than to maintain continuity with the title from the first Symposium. It was for that reason that "Assessment and Control of Metal Removal Fluids" was added in recognition of, and to call attention to the fact that the vast majority of research and data to date has been generated on a subset or class of metalworking fluids known as **metal removal fluids**. In addition to metal removal fluids, the very general term 'metalworking' fluids also encompasses the large and general classes of *metal protecting* fluids, *metal forming* fluids, and *metal treating* fluids. Besides functional differences between metalworking fluid classes, there are substantial compositional differences both between and within classes. So while it is somewhat sloppy though quite common and generally harmless to use generic terms such as metalworking fluids, or machining fluids, or coolants, the reader should be well aware of these important distinctions and that in virtually all instances where there is a connection with purported health effects, the person is really referring to that subclass of metalworking fluids known as *metal removal fluids*.

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