

Case Study: Mist Control Following Installation of Air Cleaners on Machining Centers

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ABSTRACT

At a machining center used to produce transaxle and transmission parts, aerosol instrumentation was used to quantitatively evaluate size-dependent mist generation of a synthetic metalworking fluid (MWF) consisting primarily of water and triethanolamine (TEA). This information was used to select an air cleaner for controlling the mist. During most machining operations, the MWF was flooded over the part. These machining operations were performed in a nearly complete enclosure that was exhausted to an air cleaner consisting of three sections: a fall-out chamber, a filter section to capture metal chips and mist, and a 1.13 m³/s (2400 cfm) blower.

To quantitatively study the effect of machining operations on mist generation, air was isokinetically sampled upstream and downstream of the air cleaner. The following instruments measured aerosol concentration and size distribution as a function of time: a time-of-flight aerosol spectrometer and an eight-channel optical particle counter. The observed penetration through the air cleaner was consistent with the manufacturer's specifications on the air cleaner's filters; the 95% efficient ASHRAE filters appeared to collect all particles larger than 3 μm . However, coolant accumulated on the bottom of the air cleaner and relatively large particles were being generated from this accumulated liquid. This source of mist production was eliminated by increasing the size of the drainage holes in the bottom of the air cleaner.

After modification, 25 air cleaners were installed at machining centers throughout the shop and at fluid recycling stations. The facility implemented a maintenance program for the air cleaners that involves regularly scheduled filter changes; performance is ensured by monitoring static pressure. Air sampling was conducted before and after the control measures were installed. Area triethanolamine concentrations were reduced from a geometric mean of 0.26 mg/m³ to 0.03 mg/m³. Personal total particulate concentrations were reduced from 0.22 mg/m³ to 0.06 mg/m³. These results show the effectiveness of this combination of enclosure, ventilation, and filtration to greatly reduce the exposure to MWF mist generated in modern machining centers.

INTRODUCTION

There are many health effects associated with metalworking fluid (MWF) exposures, including dermatitis,⁽¹⁾ respiratory disease,⁽²⁾ and asthma.⁽³⁾ Cross-shift decrements in lung function are reported for inhalable aerosol exposures larger than 0.2 mg/m³.⁽²⁾ Microbial contamination and endotoxins (debris from dead microbes) may also be responsible for adverse pulmonary health effects.² Some on-going research has suggested that lifetime exposures to specific types of metalworking fluids (straight, soluble, and synthetic) are associated with several digestive cancers.⁽⁴⁾ For these reasons, it is prudent to control exposures to metalworking fluids. Because of these health and other concerns, NIOSH assisted the company in an effort to reduce worker exposure to metalworking fluids by using air cleaners to control mist generated at machining centers.

This metalworking plant located in the Midwest, with approximately 300 employees in the production area, continues production 24 hours a day, with most production area employees working a 10-hour shift and a 40-hour week. Transmissions are produced for off-the-road vehicles such as lawn mowers and agricultural equipment. The iron castings that are brought into the plant are pre-shaped for the transmission. At an automated machining center, the metalworking operations, such as milling and drilling, are performed on the piece. One operator programs and tends several machines. The main source of mist emissions appeared to be the automated machining centers that were located in the L-shop. There were 12 stations in L-shop, with approximately 45 employees. These machining units were all partially or fully enclosed and automated.

At the machining centers, metalworking fluid (MWF) is used to remove metal shavings and to serve as a coolant and lubricant. At the metalworking stations examined in this study, the MWF was flooded onto the parts at a pressure of 80 pounds per square inch (psi) during approximately 70 percent of the machining cycle. During some machining operations, the coolant is forced through small holes in the drills at higher pressures ranging between 600 to 850 psi. The high-pressure

application of fluid was used during approximately 30 percent of the machining cycle. The bottom of the machining center has a sloped bottom where the excess fluid and debris are removed via a screw feeder leading to the fluid recycle system. In the L-shop, the area studied during this survey, fluid is recycled through the Hydromation unit, which is used to pump and filter the fluid, removing metal chips and other debris. The fluid used in the L-shop at approximately 12 stations was Syntilo® 9902 (Castrol Industrial North American, Inc., Downers Grove, IL), a synthetic product primarily composed of water and triethanolamine.

The company requested that NIOSH researchers perform an evaluation on the efficacy of a commercially available air cleaner. First, the NIOSH researchers characterized mist generation at the machining centers and the performance of a single air cleaner operated on one machining center. After finding that the air cleaner performance appeared to be suitable, the company installed more than 25 air cleaners on different machining centers in this plant. Then, NIOSH conducted air sampling to evaluate whether these air cleaners produced a significant reduction in air contaminant concentrations in this plant. The details of these evaluations are contained in two survey reports.^(5,6)

Air Cleaner Description

The air cleaner installed is shown in Figure 1. It is a packaged air filter unit, Model F120, manufactured by Airflow Systems, Inc. (Dallas, TX), with an approximate cost of \$4000. The units were installed over the

metalworking stations and pulled the air into the cleaning units. The air cleaner's fan moved approximately 2400 cfm through the enclosure. The air cleaner is equipped with a metal mesh prefilter, followed by a pleated "mist eliminator" prefilter. Next are the main filters, which are 95 percent efficient ASHRAE pocket filters.⁽⁷⁾ The fluids captured by the filters drip to the floor of the cleaner and exit via three drainage holes. The coolant then drains to the Hydromation recycling system. At the outlet of the cleaner is a 4-way adjustable grill for the exhaust air. While evaluating the single air cleaner, the three air cleaner drains were found to be clogged, resulting in an accumulation of metal working fluid in the bottom of the air cleaner and the emission of millimeter-size mist droplets from the air cleaner's discharge. As a result, the facility maintenance personnel enlarged the drains from 0.5 inch to 1 inch in diameter to allow proper drainage. Also, the air cleaner was tilted slightly so that it sloped toward the drains instead of the fan. Maintenance personnel reported that the exhaust grill remained clean. A maintenance program was established for the installed air cleaners. Each air cleaner was fitted with an aneroid pressure gauge to indicate pressure drop across the system. The filters are changed at 30-day intervals and thoroughly cleaned or replaced. Because the MWF tends to collect in the filters and not fully drain when a machining center is run on a 24-hour-per-day cycle, the air cleaners on these machines are turned off, i.e., rested, for 1 hour out of each 24 hours.

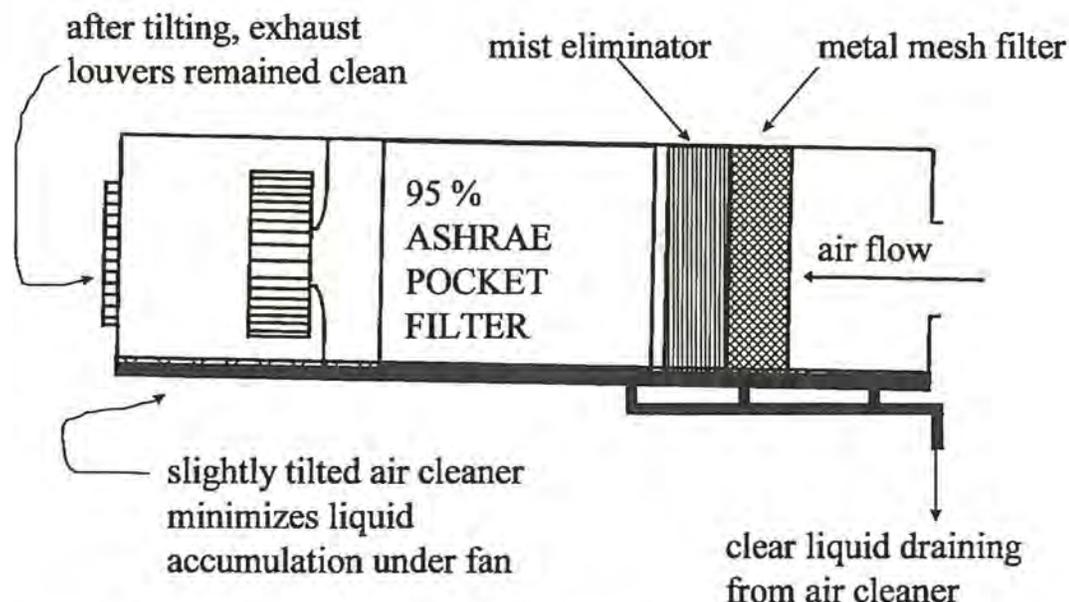


Figure 1. Observations about the operation of the air cleaner

METHODS

At a single machining center, the aerosol generation rate and size distribution were characterized. In addition, the efficacy of this air cleaner was evaluated. To do this, the mist concentration as a function of size was measured during a routine production cycle. The size-dependent mist concentrations were measured in the duct upstream of the air cleaner approximately four feet from the air cleaner inlet with the Aerosizer (Amherst Process Instruments Inc., Hadley, MA) in a test stand designed to extract isokinetic samples from a ventilation duct. In addition, the size distribution and concentration of the mist exiting the air cleaner were measured.

The Aerosizer was used with an Aero-Diluter and a vacuum pump to draw 2 lpm through a 0.75 inch inside diameter steel pipe through a preselector. In the Aerosizer, individual particles are sized based upon their transit time between two laser beams. As particles pass through the two laser beams, scattered light is detected by two photo multiplier tubes. The time difference between these two events is measured. The two laser beams are located near the exit of an acceleration nozzle. The air exits this nozzle at near sonic velocity and continues to accelerate through the measuring region. Particles are accelerated by the flow, which ultimately reaches a velocity of 500 m/sec. The drag forces operating on liquid particles may deform or break the individual mist particles, causing artifacts in the measurement. To prevent this, a preselector was used to eliminate particles whose breakup may cause anomalous results. The preselector had a D_{50} of 14 μm . The preselector was a single-stage impactor with a 6-mm diameter jet; it was the number two impaction stage from an impactor (Sierra Series 260 Marple Impactors, Sierra Instruments, Carmel Valley, CA).

After determining that the air cleaner was acceptable (see Figure 3), over 25 of these air cleaners were installed in the plant. The effect of these air cleaners upon air contaminant concentrations was evaluated by measuring the concentration of total particulate and triethanolamine before and after the control measures were implemented. Impinger samples were taken using NIOSH Method 3509 for triethanolamine (TEA).⁽⁸⁾ Pump flow rates were increased to 2 lpm. The limit of detection (LOD) was 9 $\mu\text{g}/\text{sample}$ and the limit of quantitation (LOQ) was 29 $\mu\text{g}/\text{sample}$. There were no samples reported as nondetectable. Samples that were found to be between the LOD and LOQ were estimated with the analytical laboratory reported result.

Impinger sampling was used only for area samples. Samples were taken in several areas, including "between machines," for 4-8 hour periods. Two other sites were chosen because they were at opposite boundaries of the

L-shop; the samples were denoted as "L-Shop Edge" and, near the Hydromation unit (Hydro), "central cleaning."

Personal and area samples for total weight particulate were taken according to NIOSH Method 0500.⁽⁸⁾ Area samples were taken at the same locations as for impinger samples. In addition, samples were collected on the workers in the area. Other than blanks, there was only one sample that resulted in a nondetectable level. For statistical purposes, this sample was estimated to be LOD/2, or 0.01 mg/sample.

In order to understand the workers' exposure sources, two operators were monitored by a handheld aerosol monitor (HAM), (PPM Inc., Knoxville, TN). The unit was belt mounted and the operators were videotaped as they performed various tasks including machining center adjustment and cleaning, re-mounting castings on "tombstones," checking specifications of machined castings inside a plant floor enclosed room, and making adjustments on partially enclosed machining centers.

The Portable Dust Monitor (PDM) (Grimm, Ainring Germany), an 8-channel optical particle counter, was used to measure mist concentration in the duct upstream of an air cleaner and at six locations inside the plant shop areas, the front office area on the first floor, and outside the main employee entrance. Total particulate concentration was recorded.

The optical particle counter uses the quantity of light scattered by individual particles to determine particle size, and the aerosol photometer uses the quantity of light scattered from all the particles in the sensing volume to estimate the aerosol concentration.⁽⁹⁾ As a result, the response of these instruments will vary with particle size and particle optical properties. Thus, measurements from these instruments are reported as relative concentration.

RESULTS AND FINDINGS

Figure 2 shows the effect of machining operations upon mist generation. During these machining operations, there was no mist generation at the start of the machining operation and mist concentrations were less than 0.2 mg/m^3 . Before the cutting operations began, the part was flooded with coolant. This caused a steady concentration of MWF mist between 1 and 2 mg/m^3 . This flooding coolant is termed low-pressure coolant, and coolant is always being applied except when grinding occurs and during background measurements which are noted in Figure 2. At times during the production cycle, coolant was forced through the tools at pressures as high as 850 psi. The high-pressure application of MWF caused distinct spikes in

the mist concentrations shown in Figure 2. When the high-pressure coolant was applied, it lasted for periods of 1-5 minutes, causing a concentration of MWF mist between 3-5 mg/m³. Figure 2 shows that some of these exposure peaks are much less than one minute in length. The videotape of the machining operations showed that the high-pressure coolant started no more than 1-5 seconds before the tool started performing machining operations. During high-pressure application, the coolant orifice acted essentially as a spray nozzle until the tooling was inside the part. When the fluid's energy was dissipated while flowing out of the part, there was

minimal additional mist generation attributed to the use of high-pressure coolant.

In Figure 3, average size distributions, measured upstream and downstream of the air cleaner, are presented. In these plots, the term " $\Delta C_m / \Delta \ln(d_p)$ " is plotted as a function of particle size. Clearly, the air cleaner is eliminating particles larger than 3 μm . Much of the aerosol mass appears to be in particles that are larger than 3 μm . The specific machining operation did not affect the shape of the size distribution. Thus, the choice of the ASHRAE 95% efficient filter is appropriate for this facility.

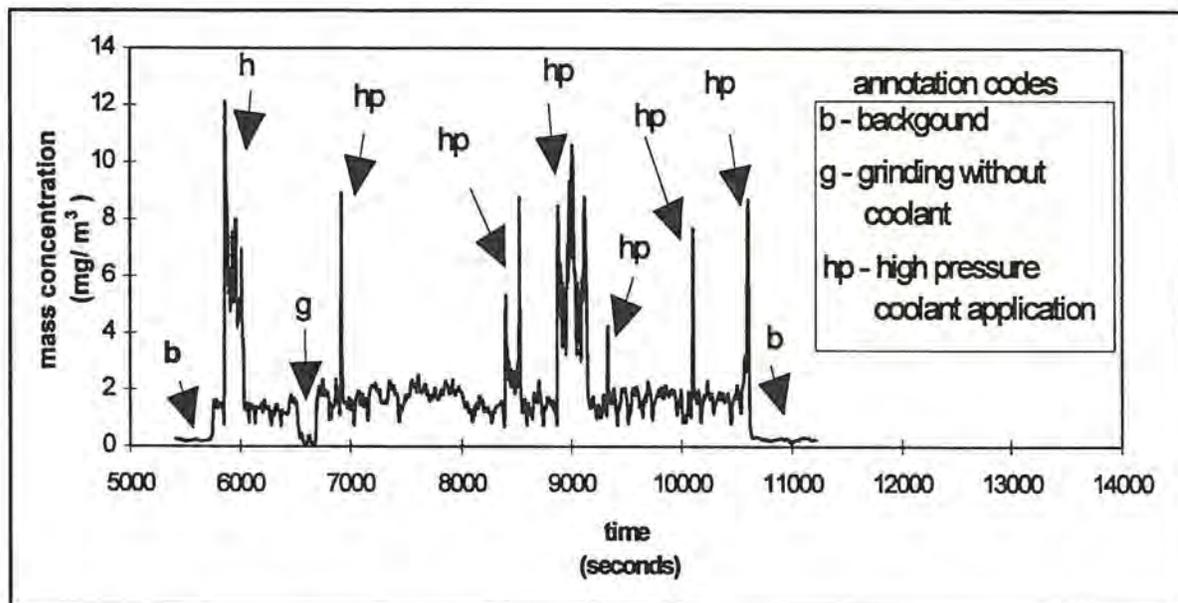


Figure 2. Mist generation, as measured with a Grimm PDM at a single machining center varied with the operation. The application of high-pressure coolant caused a noticeable increase in mist generation. The PDM was used to measure mist concentration upstream of the air cleaner.

TEA and total particulate concentrations measured before and after the air cleaners were installed on the more than 25 machining centers are summarized in Tables 1 and 2. Inspection of these tables shows decreases in concentrations by factors of 2 to 10. With the exception of the total particulate concentration measured at the "L-Shop Edge" (Table 2), these differences are all statistically significant. Installation of controls reduced workers' personal total particulate exposure from 0.22 mg/m³ to 0.06 mg/m³; however, this reduced value was higher than area concentrations measured at the "L-Shop Edge" and "between machines," based upon the Waller-Duncan k-ratio t test.⁽¹⁰⁾ Thus, the worker engages in activities which provide some minor increase in his total particulate exposure.

The results of the HAM/video-exposure monitoring in Figure 4 provide some insight into the sources of worker exposure to particulate matter. Operator A had his highest relative concentration, 0.93 mg/m³, when he was inside a machining center (#4897) "cleaning"; his second highest, 0.46 mg/m³, occurred when he was inside the L-shop floor office checking specifications (tolerances). Operator B had his highest concentration when he was at the open door, at times with his arm inside, of partially enclosed machining centers (#6922 and #6921). The relative concentrations were 0.45 to 0.63 mg/m³.

Figure 5 presents some short-term relative concentration measurements made with the PDM. The highest relative mist concentration levels were found in the flume near a machining center across the main aisle from the Hydromation (central cleaning) unit at

22.4 mg/m³; the lowest relative concentration was outside the plant at 0.018 mg/m³. Concentrations at an unventilated, partially enclosed machining center (#6902) were the next highest at 0.397 mg/m³ followed

closely by 0.284 mg/m³ over a piece of plywood covering a floor flume where a machining center had been removed. Apparently, the motion of the fluid in the flume is a source of metal working fluid mist.

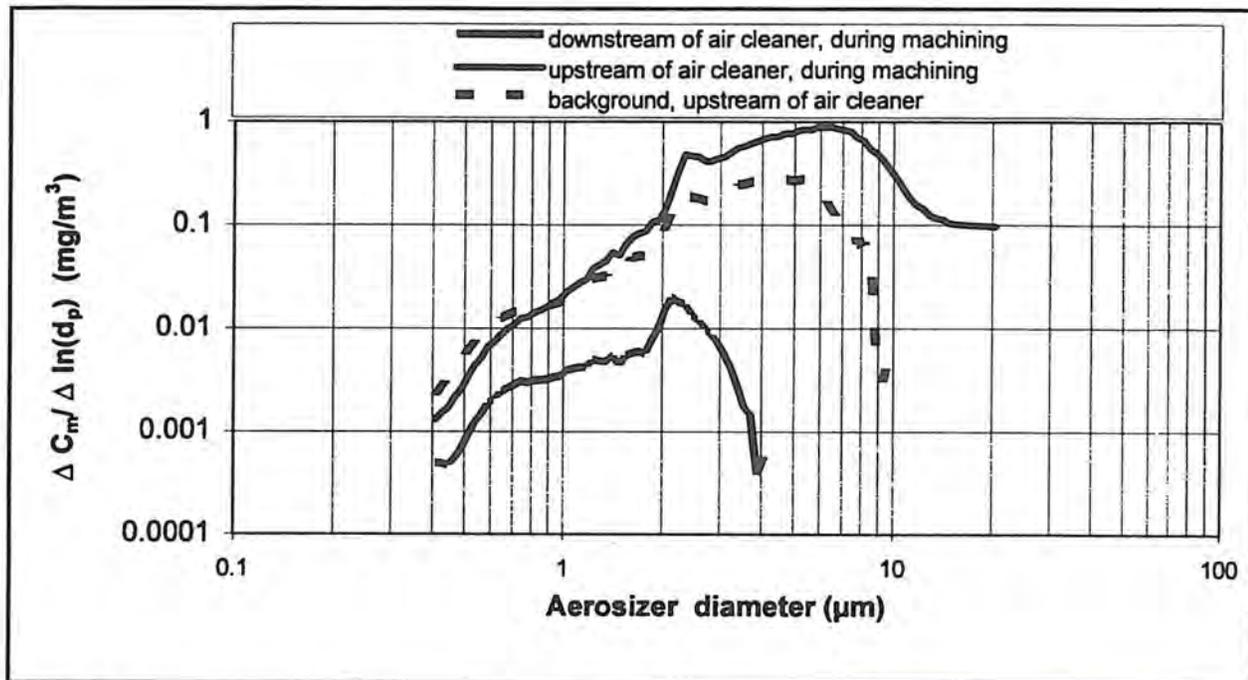


Figure 3. Comparison of size-dependent concentrations measured by the Aerosizer upstream and downstream of an air cleaner. The difference in mass concentration between two particle sizes is denoted as “ ΔC_m ”. In order to compare measurements made by different instruments which have different channel widths, this concentrations is divided by the difference in the natural logarithms of the particle diameters which is termed “ $\Delta \ln(d_p)$ ”. Apparently, the air cleaner eliminates practically all of the particles larger than 3 μm .

Table 1. Summary Statistics for Triethanolamine Concentrations

Location	August 1995			August 1996			Significance of Concentration Reduction Probability > F
	N	GM (mg/m ³)	GSD	N	GM (mg/m ³)	GSD	
Between Machines	5	0.25	1.34	6	0.03	1.21	0.0001
Central Cleaning (Hydro unit)	6	0.43	1.38	6	0.04	1.23	0.0001
L-Shop Edge	6	0.11	2.21	6	0.03	1.26	0.0024

Based on a one-way analysis of variance (ANOVA) using log transformed data.^(10,11)

N = Number of Samples; GM = Geometric Mean; GSD = Geometric Standard Deviation

Table 2. Summary Statistics for Total Particulate Concentrations

Location	August 1995			August 1996			Significance of Concentration Reduction
	N	GM (mg/m ³)	GSD	N	GM (mg/m ³)	GSD	Probability >F
Between Machines	6	0.25	1.72	5	0.02	1.77	0.0001
Central Cleaning (Hydro unit)	6	0.48	1.59	6	0.03	1.33	0.0001
L-Shop Edge	6	0.07	2.20	6	0.03	2.76	0.0960
Worker (Personal)	18	0.22	1.59	16	0.06	1.50	0.0001

Based on a one-way analysis of variance (ANOVA) using log transformed data.^{10,11}
 N = Number of Samples; GM = Geometric Mean; GSD = Geometric Standard Deviation

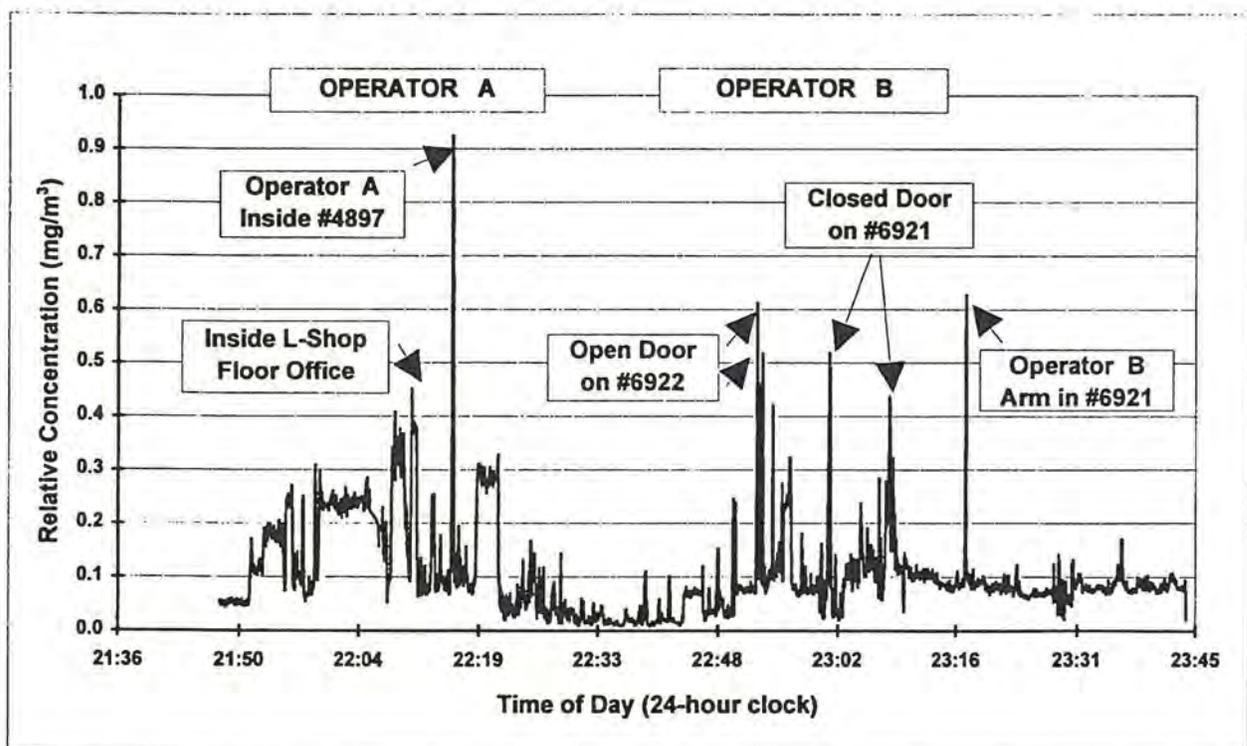


Figure 4. Effect of work activities upon mist exposure after the air cleaners were installed. The workers' mist exposure as monitored with an aerosol photometer.

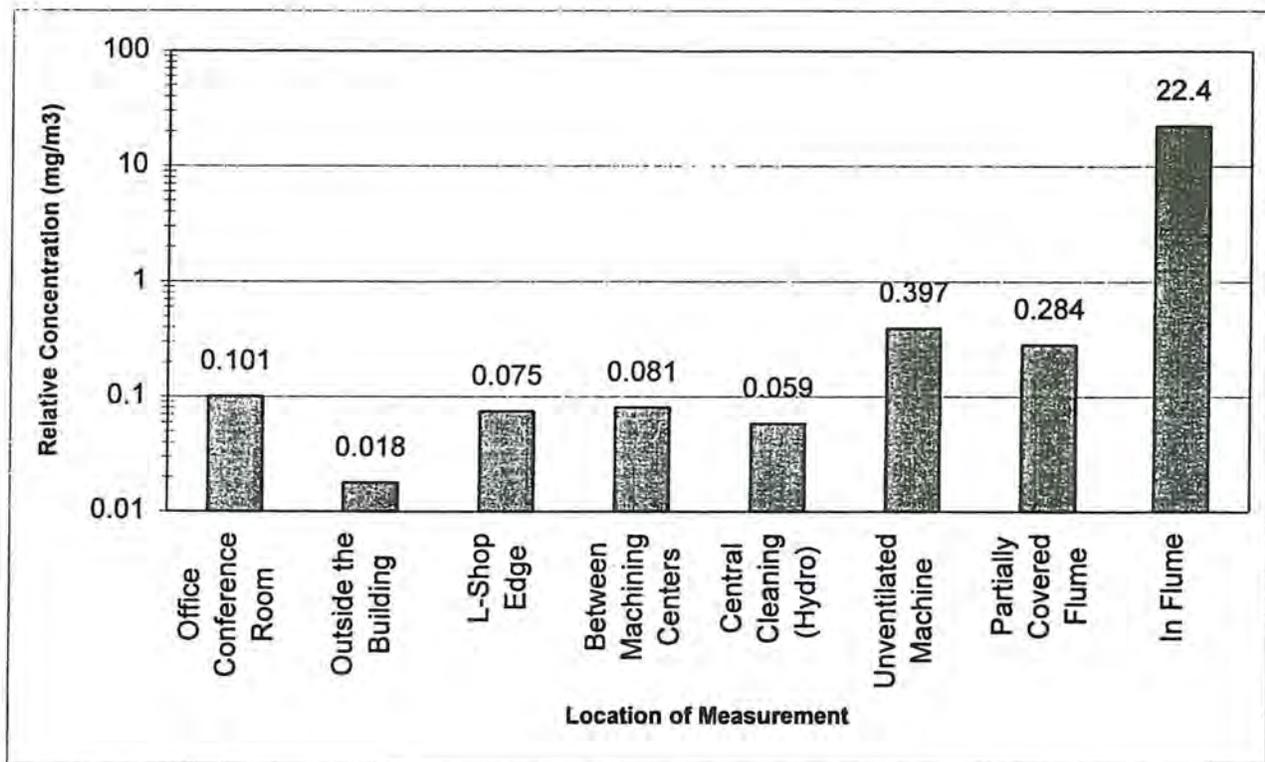


Figure 5. Total particulate matter concentrations as measured by Grimm PDM at several locations. Apparently, unventilated machines and uncovered flumes can be noticeable sources of mist emissions.

DISCUSSION AND CONCLUSIONS

The preliminary work conducted with a single air cleaner showed that the mist aerosol had a particle size mode of about 8-10 μm . The use of high-pressure coolant appears to increase the mist emissions. Installing the air cleaners on the machining centers and controlling the mist emissions from the Hydromation unit reduced triethanolamine concentrations four-to-ten fold. The total particulate concentrations were reduced 16 fold near the Hydromation unit, the location of highest concentration in the "before" study. The concentrations were significantly improved in the other area samples and in the personal samples.

As noted earlier, mist exposures in this facility were reduced from a geometric mean of 0.22 mg/m^3 to 0.06 mg/m^3 for the total particulates. In fact, no sampled worker's exposure exceeded 0.15 mg/m^3 after the controls were implemented. This effective mist control was obtained because the worker was separated from most of the mist generation sources. The automated machining centers isolated and separated the workers from much of the mist generation caused by the machining operations. The air cleaners installed on

these machining centers prevented the mist from entering the workplace. The metalworking fluid flumes were mostly enclosed and the fluid treatment unit was enclosed and ventilated to control mist generated by fluid movement. When these control measures were absent, mist generation was observed with the optical particle counter.

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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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