IN-DEPTH SURVEY REPORT

CHARACTERIZATION OF METALWORKING MISTS DURING THE EVALUATION OF A COMMERCIAL AIR CLEANER

AT

SAUER SUNDSTRAND
Ames, Iowa

REPORT WRITTEN BY
William A Heitbrink
Amy Beasley Spencer
Gregory J Deye

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U S DEPARTMENT OF HEALTH AND HUMAN SERVICES
Public Health Service
Centers for Disease Control and Prevention
National Institute for Occupational Safety and Health
Division of Physical Sciences and Engineering
Engineering Control Technology Branch
4676 Columbia Parkway, Mail Stop R5
Cincinnati, Ohio 45226-1998

PLANT SURVEYED	Sauer Sundstrand Company 2800 E 13 Street Ames, Iowa 50010
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EMPLOYER REPRESENTATIVE CONTACTED	Mark Sullivan Safety Manager
SURVEY CONDUCTED BY	William A Heitbrink Amy Beasley Spencer Gregory J Deye Daniel S Watkins John M Yacher Chandra Baker
EMPLOYEE REPRESENTATIVES CONTACTED	No Union
MANUSCRIPT PREPARED BY	Bernice L Clark

ABSTRACT

At a machining center used to produce transmission parts, aerosol instrumentation was used to quantitatively evaluate size-dependent mist generation of a synthetic metalworking fluid (mwf) This information was needed to evaluate the performance of an air cleaner for controlling the mist This machining center drilled and tapped holes at rotational speeds of 1000 to 3000 rpm During most machining operations, the mwf was flooded over the part To facilitate metal chip removal during some operations, mwf was pumped through the orifices in some tools at a pressure of 800 psi Such high pressure may create a very fine mist These machining operations were performed in a nearly complete enclosure that was exhausted to an air cleaner The air cleaner's fan moved approximately 2000 cfm through the enclosure, an elbow, and 15 feet of 14 inch diameter duct that connected the air cleaner inlet to the enclosure To quantitatively study the effect of machining operations upon mist generation, an air sample was isokinetically sampled from the duct and drawn into a sampling plenum at a flow rate of 85 liters per minute In this plenum, the following instruments were used to measure aerosol concentration and size distribution a time of flight aerosol spectrometer (the Aerosizer Mach 2, Amherst Process Instruments, Hadley, MA), a quartz crystal microbalance cascade impactor (model PC2, California Measurements, Sierra Madre, CA), and an eight-channel optical particle counter (Portable Dust Monitor Model 1105, Grimm Ainring, Germany) This sampling system was used to characterize the aerosol flowing into and out of the air cleaner In addition, an aerosol photometer (RAM-1, MIE Inc , Bedford, MA) was used to continuously monitor the aerosol concentration The aerosol photometer and optical particle counter measurements showed that mist generation was relatively constant until the mwf was pumped through the tools at 800 psi Although this increased the mist concentration by about 300 percent, it did not affect the mist size distribution

The observed penetration through the air cleaner appeared to be mostly consistent with the manufacturers specifications on the air cleaner's filters The filter should have collected all particles larger than 3 µm However, data taken with the optical particle counter and the quartz crystal microbalance impactor showed that particles larger than 3 µm were emitted from the air cleaner During the testing, metalworking fluid was observed to accumulate in the bottom of the filter housing, and this mist may have been reentrained due to air motion or mechanical vibration

In addition to evaluating air cleaner performance, the concentration of particulate and triethanolamine were measured These measurements suggested that the metalworking fluid recirculation and filtration unit, referred to as the "hydromation unit", are an additional source of metalworking fluid emissions

INTRODUCTION

Sauer Sundstrand, Inc is a metalworking plant located in Ames, Iowa In this location, there are approximately 300 employees in the production area There are approximately 200 office area employees Sauer Sundstrand continues production 24 hours a day, with most production area employees working a 10 hour shift, 40 hour week Transmissions are produced for off the road vehicles such as lawn mowers and agricultural equipment The steel castings which are brought in the plant are pre-shaped for the transmission Additional metalworking is performed on the piece, including milling and drilling Each metalworking station is automated One operator programs and tends several machines

Metalworking fluid (mwf) is also referred to as coolant, and the two terms will be used interchangeably throughout the text It is used during the metalworking to remove metal shavings and to serve as a coolant and lubricant At the metalworking station examined in this study, the mwf was flooded onto the part at a pressure of 80 psi During some machining operations, the coolant is forced through small holes in the drills at higher pressures ranging between 600 to 850 pounds per square inch (psi) The high pressure application of fluid was used during approximately 30 percent of the machining cycle In other machines, other coolant applications may reach pressures as high as 1200 psi During the high pressure application of coolant, the tooling rotations reached as high as 4500 rpm, with an average of 1000 rpm The lower pressure applications flooded the part with the fluid at relatively low pressures, around 80 psi, approximately 70 percent of the machining cycle The bottom of the machining station 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 a "hydromation" unit The hydromation unit storage pit has a volume of 10,000 gallons The hydromation unit 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 (Castro Industrial, Inc , Downers Grove, IL), a synthetic product primarily composed of water and triethanolamine Several different types of mwf are used throughout the plant at approximately 250 metalworking stations

The main focus of this study was L-shop where it was thought that the majority of plant metalworking fluid mists were generated In L-shop, metalworking was performed on items with a low volume total to be produced High quantity orders were done elsewhere in the plant There were 12 stations in L-shop with approximately 45 employees These machining units were all partially enclosed and automated At one of the Toyoda manufactured metalworking stations in L-shop, an air cleaner was installed to remove the mwf aerosols before recycling the air into the plant

Air Cleaner Description

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

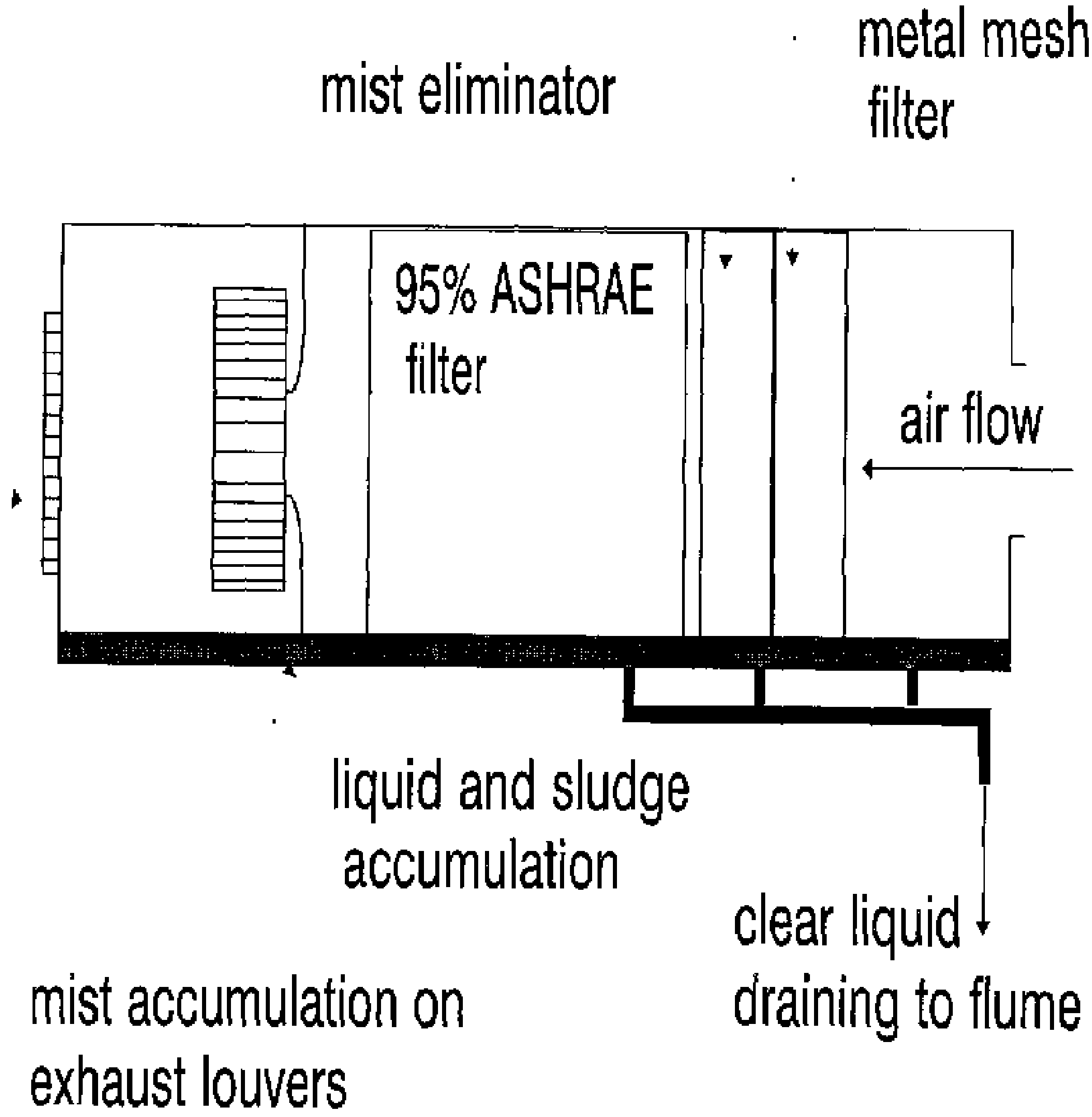

Figure 1 Installed air cleaner, including qualitative observations of mwf accumulation noted during the second phase of the study

metalworking station and pulled the air up into the cleaning unit The air cleaner's fan moved approximately 2400 cfm through the enclosure, elbow, and 15 feet of 14 inch diameter duct that connected the air cleaner inlet to the enclosure Figure 2 shows the schematic illustration of the duct work located on top of the machine 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 According to ASHRAE guidelines, a 95 percent efficiency filter removes all particles with a diameter of approximately 2 μm The general efficiency curve of this filter also shows a minimal efficiency of approximately 72 percent for particles sized near 0 3μm [1] 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 exiting air

Study Objectives

Sauer Sundstrand, Inc requested that NIOSH researchers perform an evaluation on the efficacy of a commercially available air cleaner This air cleaner would be placed downstream from a metalworking station, and the "cleaned" air would be recirculated into the plant, thus saving heating and cooling costs The recirculation would also eliminate the need for an exhaust stack for the numerous stations, also, there are significant time-delays associated with obtaining stack permits from local air pollution control agencies In order to meet production demands, and to save money, the air is circulated through an air cleaner and the discharged air is recycled to the plant Thus, there is a need to evaluate the efficacy of air cleaners for oil mists Sauer Sundstrand hoped to gather additional information in order to decide if this type of air cleaner should be installed throughout the plant on each of the metalworking stations One of NIOSHs goals for conducting this in-plant study was as a prelude to pilot plant studies to evaluate the effect of machining parameters upon size dependent mist concentrations Two of the main issues to be examined included the following

- Characterization of the aerosol produced during metalworking How do machining operations affect the size-dependent mist concentrations? The size distribution of the incoming mist is a key consideration in the selection of an air cleaner If the mist size is too small, the mist can flow straight through the air cleaner

- Establish the efficacy of this air cleaner for reducing worker exposure to mwf Two surveys were conducted to gather this information The first study was conducted in June 1995 to experimentally evaluate the test stand designed and built by NIOSH researchers in order to characterize the aerosol, this initial evaluation is referred to as "Phase 1" During the second evaluation, conducted in August 1995, air contaminant concentrations were measured This part of the project is referred to as "Phase 2"

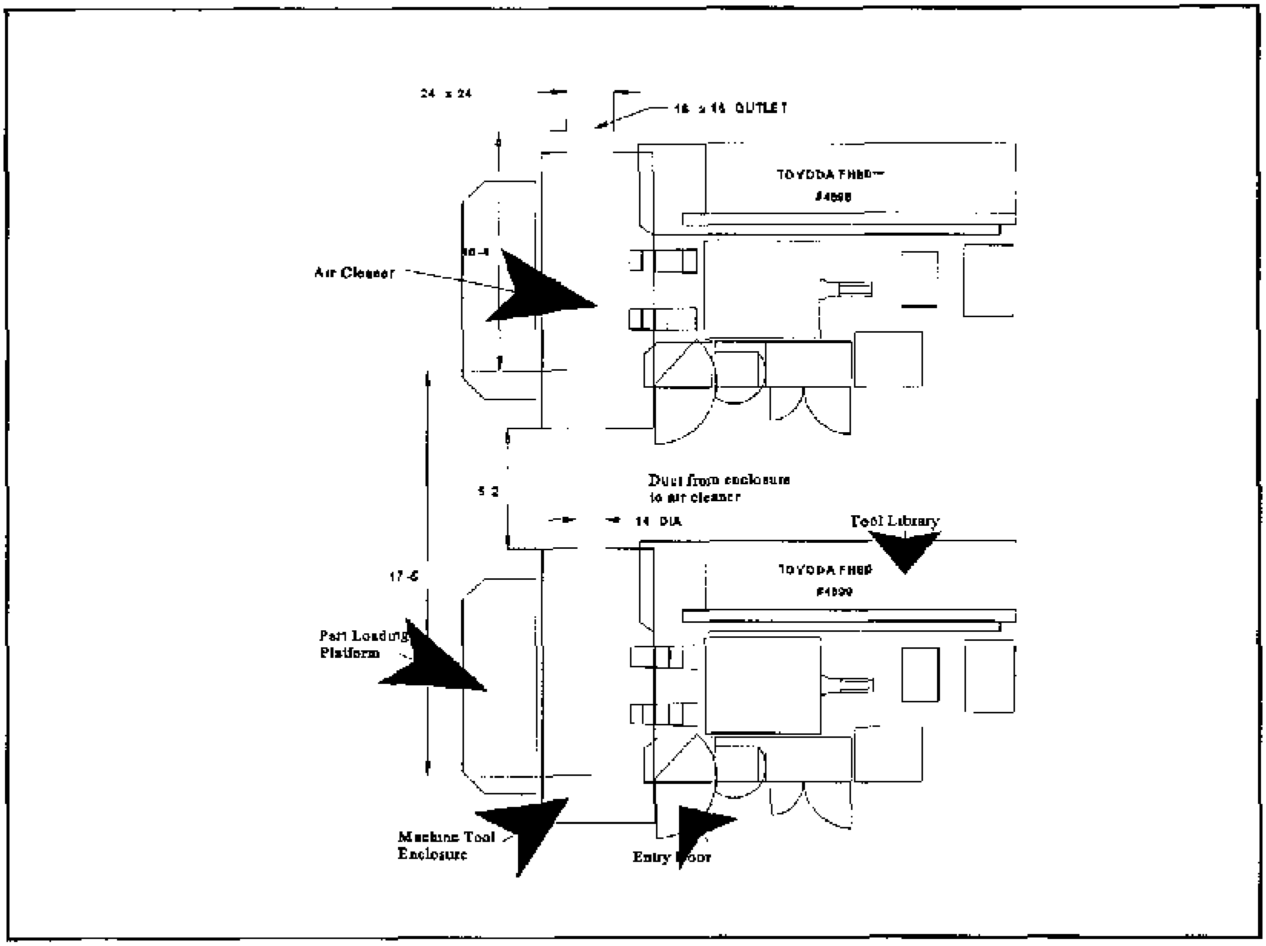

Figure 2 Schematic illustration of duct work located on top of machine

Health Effects

There are many health effects associated with metalworking exposures including dermatitis[2], respiratory disease[3], and asthma[4] Cross-shift decrements in lung function are reported for inhalable aerosol exposures larger than 0 2 mg/m^3 Microbial contamination and endotoxins (debris from dead microbes) may also be responsible for adverse pulmonary health effects[6] 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[5] For these reasons, it is prudent to control exposures to metalworking fluids

Exposure Evaluation Criteria

Triethanolamine is the major component of the synthetic mwf used during this study For triethanolamine, the American Conference of Governmental Industrial Hygienists has established a Threshold Limit Value of 5 mg/m^3 as an 8-hour time weighted average[6] The ACGIH is private organizations and its TLVs refer to airborne concentrations to which nearly all workers may be repeatedly exposed without experiencing adverse health effects

The Occupational Safety and Health Administration (OSHA) has established a permissible exposure limit for particulate not otherwise regulated of 15 mg/m^3 as an 8-hour time weighted average[7]

EXPERIMENTAL PROCEDURES - PHASE 1

The experimental objectives were addressed by measuring the mist concentration as a function of size upstream and downstream of the air cleaner during a routine production cycle The test stand shown in Figure 3 was used to draw an air sample into an air sampling chamber The size dependent mist concentrations were measured in the duct upstream of the air cleaner as shown in Figure 4 The measuring position was approximately 4 feet from the air cleaner's inlet and approximately 10 feet from the elbow connecting the metalworking stations's enclosure to the duct Size-dependant mist concentrations were also measured at the exhaust louvers as shown in Figure 5

Test Stand Construction

The test stand was designed and constructed for extracting an isokinetic sample from an exhaust duct The air samples enter the chamber through a 0 5 inch diameter nozzle which expands to an exit diameter of 1 5 inches in a horizontal distance of 3 5 inches The nozzle was fabricated from 0 004 inch thick brass shim stock After flowing into the nozzle, the air flows into a 2 inch horizontal length of a copper tubing into copper elbow (1 5 inch diameter, 3 inch radius) The elbow was connected to a 53 inch length of 1 5 inch diameter copper tubing The air flowed out

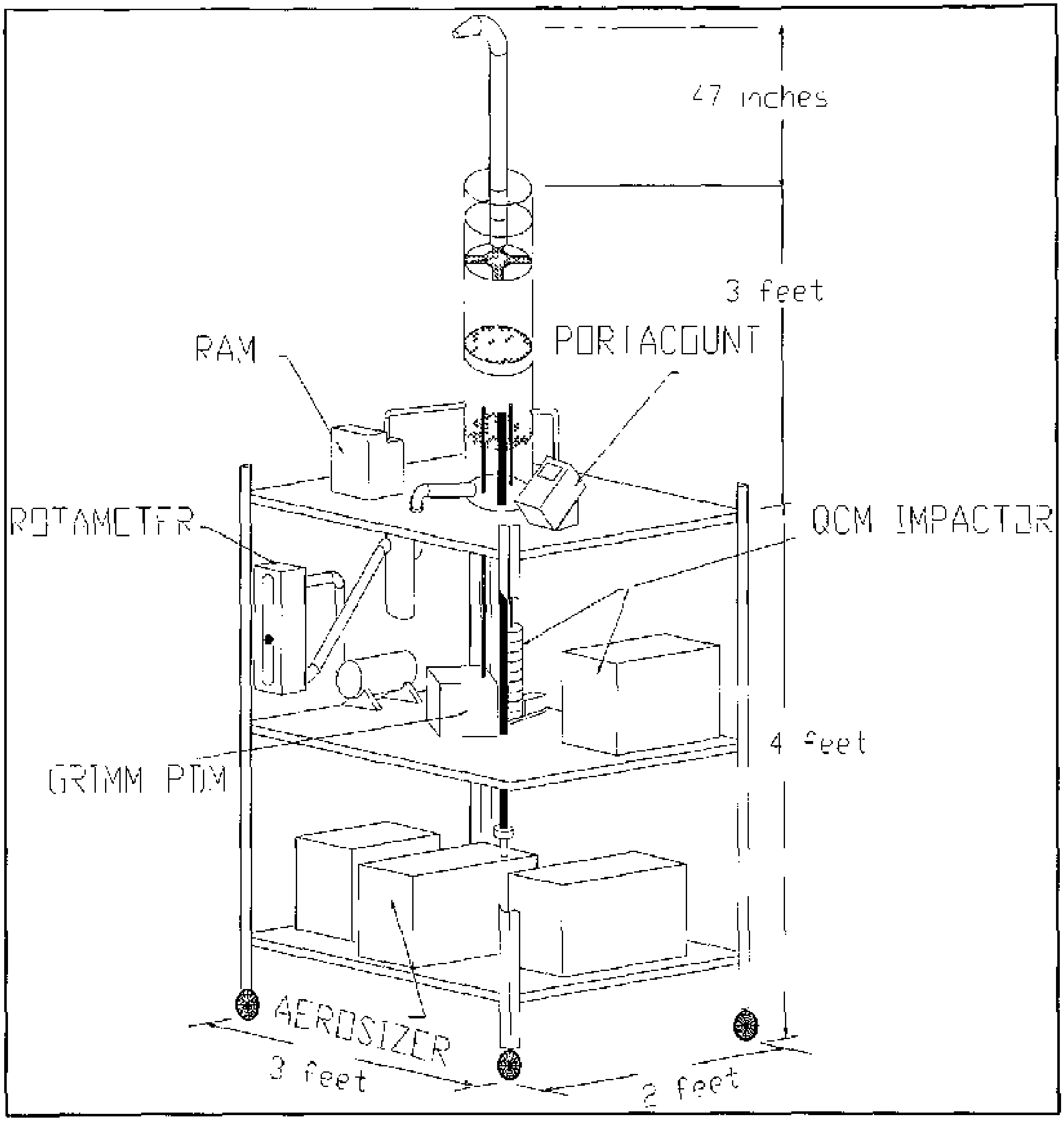

Figure 3 The test stand for extracting isokinetic samples from the duct and measuring the size distribution of the mist

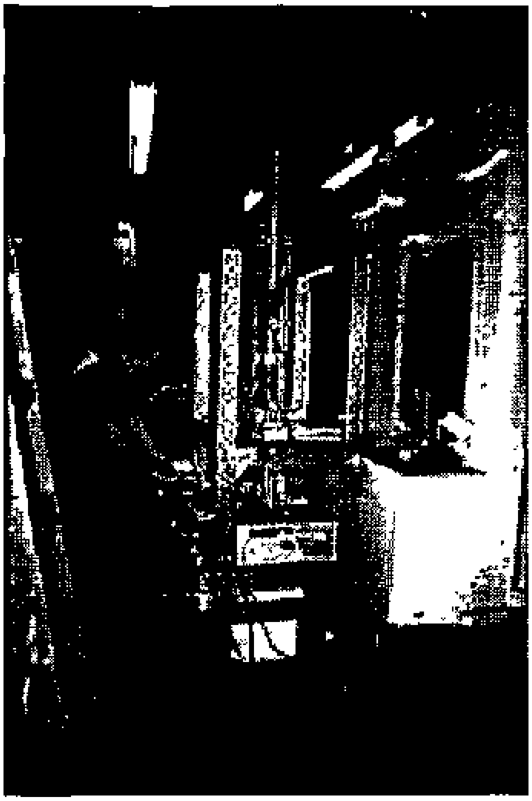

Figure 4 Sampling the air in the duct upstream of the air cleaner

Figure 5 Sampling the air that flows out the exhaust louvers Note the use of cardboard in an effort to somewhat isolate the exhaust air from the air in the plant

of the copper tubing into a six inch diameter plastic tube In the plastic tube, the air flowed past a baffle, which was intended to induce turbulence, to mix the air, it then went through a flow straightener The inlet to the sampling instruments (which are listed below) was located between the flow straightener and a perforated metal plate which served to evenly distribute the air flow for air sampling Air was drawn through this test stand by a vacuum pump and other pumps associated with the instruments In order to protect the vacuum pump, the air flowed out of the test chamber through a cartridge filter (Speedaire Part 62949, Dayton Electric Mfg Co, Chicago, IL) The flow rate was controlled by a rotameter (Serial no 096196, Cole Parmer, Niles, IL)

Instrumentation

The instruments below were used during sampling, and were placed after the flow straightener in the test stand

- The Portable Dust Monitor (PDM), (model 1 105, Grimm Labortechnick GmbH&Co, Ainring, Germany)

The PDM is an optical particle counter, which sampled through a 22 inch long 0 25 inch diameter at a flow rate of 1 2 liters per minute The PDM counts individual particles and classifies particles based upon the amount of light scattered by the individual particle For a series of sequential 6 second periods, this instruments' RS-232 output lists the number of particles larger than 0 75, 1 0, 2, 3 5, 5, 7 5, 10, 15 μm and the time This RS-232 output was recorded by operating a terminal program (Procom Plus, Datastorm Technologies, Columbia, MO) on a portable computer The instrument and the data logging were operated continuously throughout the data collection

- Quartz Crystal Monitor (QCM) Cascade Impactor (model PC-2, California Measurements Inc, Sierra Madre, CA)

The QCM draws 0 25 lpm of air from the air sampling through 12 inches of 0 38 inch inside diameter steel tube In the QCM, the air flows through a series of progressively smaller jets which forces the air to flow around piezoelectric crystals which sense the mass collected after each impaction jet As the diameter of the jets decreases, the air velocity increases, and particles with smaller aerodynamic diameters are collected on the piezoelectric sensors The vibration frequency of these crystals is measured The changes in the vibrational frequency is used to compute the mass of aerosol collected on each impaction stage The particle diameter for which an impaction stage is 50 percent (by mass) efficient is termed the 50 percent cut-off diameter (D_{50}) There is some disagreement between the theoretically estimated and experimentally determined values of D_{50} determined by Fairchild and Wheat [8] In analyzing the data, their experimental data was used These data are shown in Table 1 This instrument is used to take short term samples (30-900 seconds) The sampling time was varied in order to collect measurable masses of aerosol on the impaction surfaces without overloading the piezoelectric crystals

- A Time-of-flight Aerosol Spectrometer (Aerosizer), (Aerosizer Mach 2, Amherst Process Instruments, Hadley, MA)

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

Table 1 Theoretical and Experimental Values of D_{50} for Unit Density Spheres for California Instruments QCM Obtained by Fairchild and Wheat[9]

Stage	Theoretical (μm)	Experimental (μm)
1	24	17
2	9.4	13
3	9.2	9
4	4.6	3.9
5	2.3	1.8
6	1.3	1.2
7	0.62	0.64
8	0.4	0.34
9	0.23	0.26
10	0.14	0.14

are located near the exit of an acceleration nozzle. The air exits this nozzle at near sonic velocity and continues to accelerate as through the measuring region. Particles are accelerated by the drag forces generated by the accelerating air 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. Liquid droplet deformation is reported in another time of flight aerosol spectrometer that operates at lower velocities.[10] To prevent this, a preselector was used to eliminate particles whose breakup may cause anomalous results. The preselector had a D_{50} of 14µm. The preselector was a single stage impactor with a 6 mm diameter jet, it was the number two impactor from a collection of Marple Impactors (Sierra Series 260 Marple Impactors, Sierra Instruments, Carmel Valley, CA).

The details of the connection between the Aerosizer, the impactor, and the steel pipe are shown in Figure 6.

- Aerosol Photometer - Real-time Aerosol Monitor (RAM-1), (MIE Inc., Bedford, MA)

The RAM-1 continuously sampled the air from the side of the air sampling plenum as shown in Figure 3. The RAM-1 was operated on the 0-2 mg/m^3 range and at a time

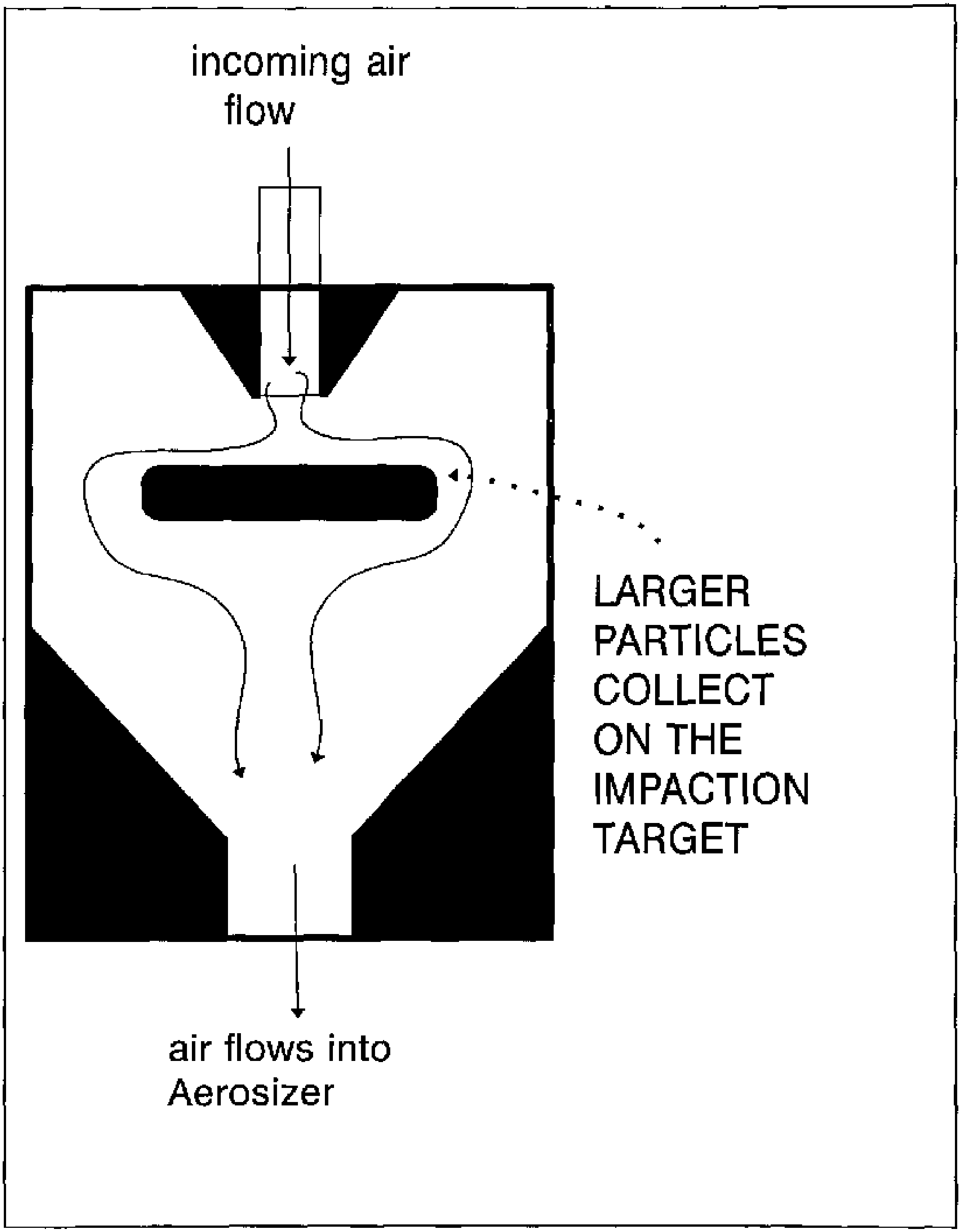

Figure 6 Details of connection between Aerosizer, impactor and pipe

constant of 2 seconds In the instruments sensing chamber, the RAM measures the quantity of light scattered by the entire cloud The quantity of scattered light is a function of concentration and the aerosol's optical properties Thus, this instrument's response is a measure of relative concentration The analog output of this instrument was recorded using a data logger (Ranger II, Rustrack, East Greenwich, RI)

- <u>Condensation Nuclei Counter - the Portacount</u> (Model 8010 Portacount™, TSI Inc , St Paul, MN)

  The Portacount samples at a flow rate of 0 7 liters per minute In order to count particles too small to be detected by an optical particle counter, the Portacount increases the particles to a larger size by condensing alcohol on individual particles After the particles' sizes are increased, the particles are counted by detecting pulses of light scattered by individual particles The RS-232 output of the Portacount was collected by using a terminal program (Procom Plus, Datastorm Technologies, Columbia, MO) on a personal computer Throughout data collection, the recorded number concentration continuously decreased Apparently, as the alcohol in the reservoir was depleted, the particles to a larger size by condensing alcohol on individual particles After the particles' sizes are increased, the particles are counted by detecting pulses of light scattered by individual particles The RS-232 output of the Portacount was collected by using a terminal program (Procom Plus, Datastorm Technologies, Columbia, MO) on a personal computer Throughout data collection, the recorded number concentration continuously decreased Apparently, as the alcohol in the reservoir was depleted, the Portacount detection limit shifts to larger sizes Note that the Portacount is intended for respirator fit testing and was never intended to be used for monitoring concentration As a result, the monitoring results from the Portacount are not included in this report, and there is no further mention of the Portacount in this report

  Other instrumentation included a temperature/humidity probe (RR2-252, Rustrack Instruments, East Greenwich, RI) The temperature and humidity was measured at the outlet of the air cleaner The temperature sensor is a thermistor and the humidity sensor is based upon thin film capacitance The readings from this probe were recorded by a data logger (Ranger II, Rustrack Instruments, East Greenwich, RI)

Flow Rate of Test Stand and Ventilation Measurements

In order to collect an isokinetic sample from the duct upstream of the air cleaner, the average duct velocity and flow rate was determined by conducting a 10-point, equal area pitot tube traverse in the duct [11] Based upon the pitot tube traverse, the average flow rate in the duct was 2170 feet per minute (fpm) Based upon a probe diameter of 0 5 inches, a flow rate of 85 liters per minute (lpm) was needed to achieve isokinetic sampling conditions This flow rate was achieved by setting the rotameter to a flow rate of 80 lpm The instrumentation provides an additional 5 liters per minute of air flow rate A velometer (Velocicalc, TSI Inc , St Paul, MN) was used to measure the air velocities at the outlet The velometer showed that air velocities were between 2000 and 2400 fpm Therefore, the test stand flow remained at 85 lpm

Testing Procedure

The sampling period started when the part holder with the part to be machined, the "tombstone", entered the machining station The sampling was terminated when the last machining operation stopped For each sampling period, a list of machine tools used was obtained from the programs used to operate the machining centers This list noted whether high pressure coolant was applied and what type of metalworking operation occurred As described in the following table, mist concentrations were measured during three different time periods

Run Number	Sampling Location	Date	Time
Run 1	Upstream of Air Cleaner	June 13, 1995	9 20 - 11 00
Run 2	Upstream of Air Cleaner	June 13, 1995	15 29 - 16 50
Run 3	Air Cleaner's Exhaust Louvers	June 14, 1995	12 16 - 13 37

RESULTS AND DISCUSSION - PHASE 1

Before Phase 1 of the study, a manufacturer of air cleaning equipment provided the facility with measurement results taken with a mass monitor The air cleaner was not installed at this time Near where the air cleaner was installed, concentrations ranging from 2 6-3 2 mg/m^3 were measured Near the hydromation unit, concentrations were recorded at 3.1 mg/m^3 [12]

During Phase 1 of the study, the installed air cleaner had been in-service for approximately two months It was visually observed that the outlet louvers of the air cleaner were coated with mwf, and that the mwf would occasionally spurt or drip out from the louvers It was thought that perhaps the filter was not seated properly, allowing the coolant to flow around the filter instead of through it However, later during Phase 2, when the filter was taken down and examined internally, drainage problems were found The three small drains were clogged with debris, including metal shavings The accumulations are shown in Figure 1 There was a half inch depth of standing mwf in the base of the air cleaner The drainage holes were enlarged to allow proper fluid removal It is probable that the air flow entrained some of the fluid as a mist

Temperature and Humidity

During three periods, temperature and relative humidity data were recorded However, the temperature and humidity data for the second run on June 13 were lost The following table summarizes the data

Date	Temperature (°F)	Percent Relative Humidity
6/13/95 (Run 1)	73-79	42-56
6/13/95 (Run 2)	---	---
6/14/95 (Run 3)	75-79	75-85

The water will evaporate from the droplets until the vapor pressure of the water in the droplet is lower than the vapor pressure of water in the air [13] As the mist droplet dries, the water content of the mist droplet decreases, thus decreasing the vapor pressure of water on the droplet's surface At very low concentrations in an ideal liquid mixture, the low concentration components exert a vapor pressure which is only a small fraction of the saturation vapor pressure [14] Thus, water may not completely evaporate from the mist droplet Because the mist may contain some water, the aerosol instrumentation may be overestimating the metalworking fluid mist concentration Thus, the aerosol intrumentation is probably overstating the mist concentration and correctly stating the mist's size However, in selecting air cleaning equipment, the size distribution of the air contaminant is a more important consideration

Aerosol Measurement

The summary of mist concentration measurements are shown in Appendix I The digital output of the Aerosizer and the PDM is reported as a number concentration The number concentrations were used to compute the mass concentration (C_m) of metalworking fluid mist, using root mean diameter (d), and assuming unit density (ρ), with n denoting the number of channels

$$C_m = \sum_{i=1}^{n} [\frac{\pi d_i^3 \rho}{6}]$$

Figures 7-9 show the response of the PDM and the RAM with time during machining operations during two sampling sessions conducted upstream Because of a data logger failure, RAM data is only available during the first session During these machining operations, there was no mist generation at the start of the machining concentrations and mist concentrations are 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

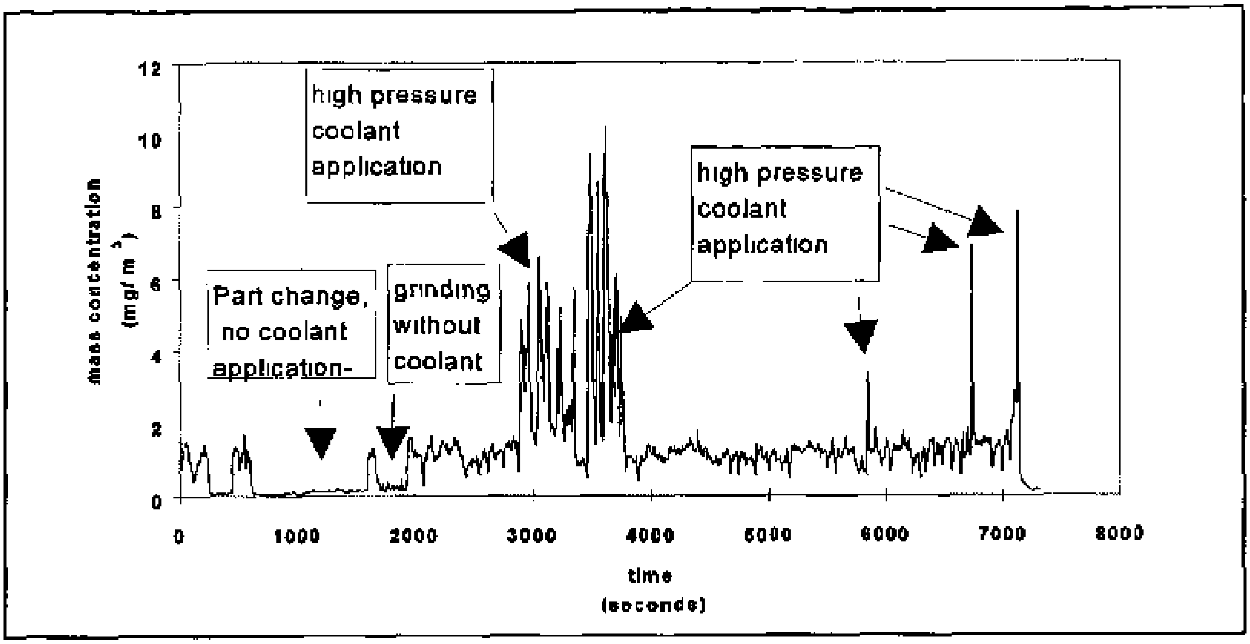

Figure 7 Mist concentration measured by the Grimm PDM during Run 1

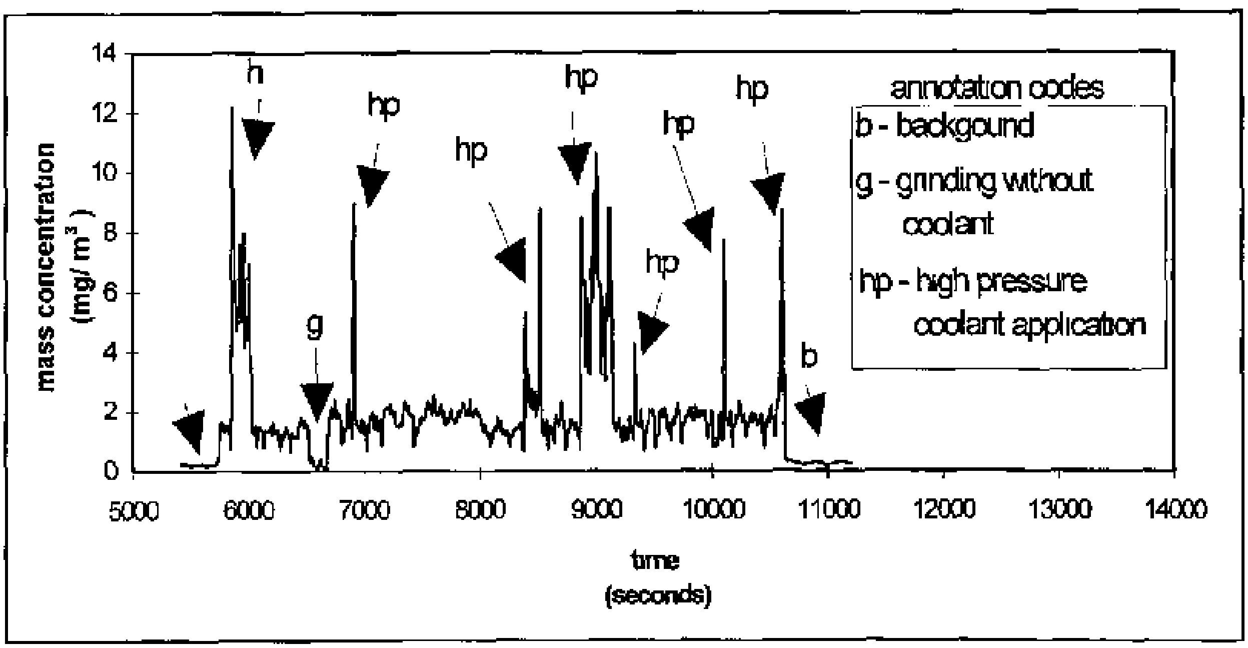

Figure 8 Mist concentration measured with the Grimm PDM upstream of air cleaner during Run 2

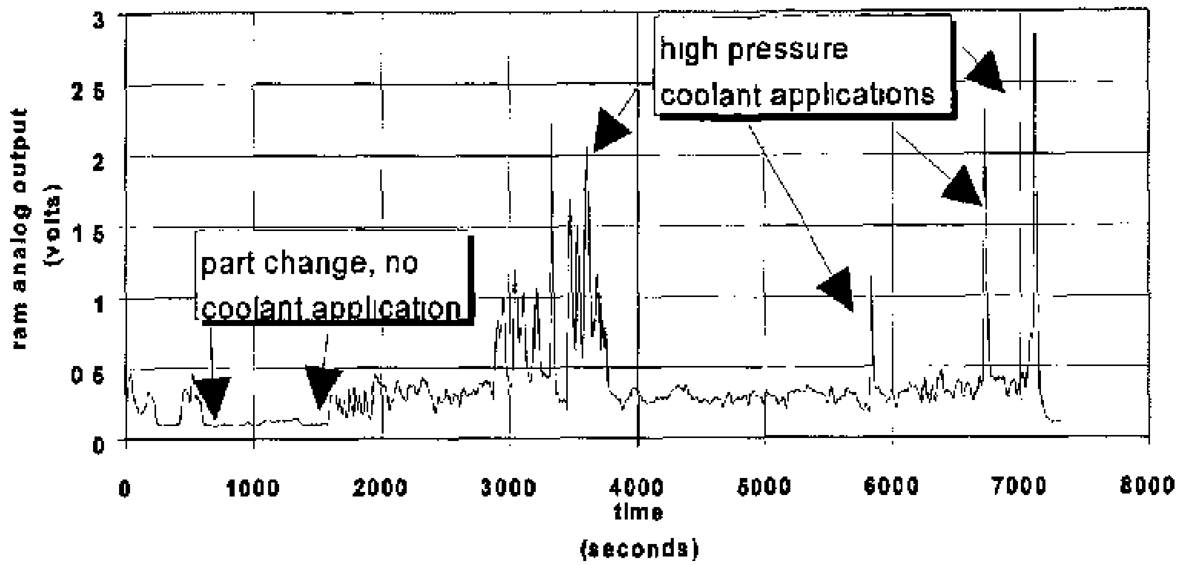

Figure 9 RAM's analog output during Run 1, the first sampling session

pressure coolant, and coolant is always being applied except when grinding occurs and during background measurements which are noted in Figures 7-9. These figures represent particles larger than 0.7 μm. 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 Figures 7 and 8. When the high pressure coolant was applied, it lasted for periods of 1-5 minutes, causing a concentration of mwf mist between 3-5mg/m^3. Figures 7 and 8 show 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 machining tool 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 Figures 10-12, average size distributions, measured upstream of the air cleaner, are presented for these conditions: 1) background aerosol measured in the absence of machining operations, 2) grinding without coolant application, 3) machining with low pressure coolant application, and 4) machining with both high and low pressure coolant application. In these plots, the term "$\Delta C_m/\Delta \ln(d_p)$" is plotted as a function of particle size. The difference in mass concentration between two particles sizes is denoted as "ΔC_m". In order to compare measurements made by different instruments which have different channel widths, this concentration is divided by the

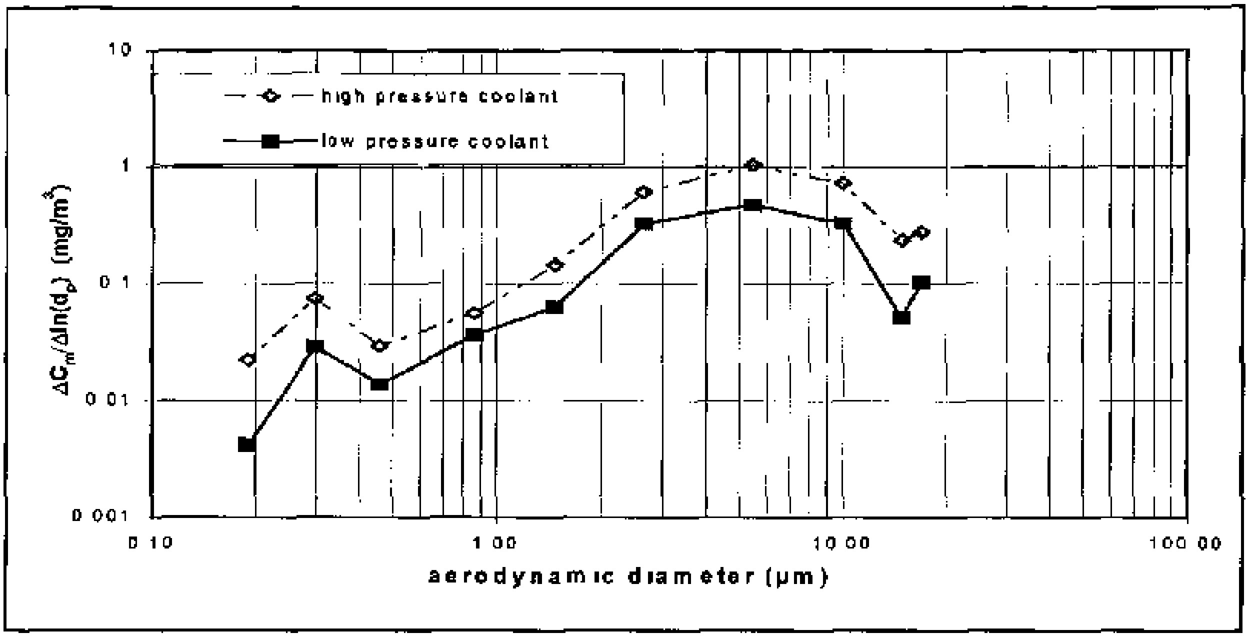

Figure 10 Fluid application pressure effects the amount of metalworking fluid aerosol measured by the California Instruments Impactor

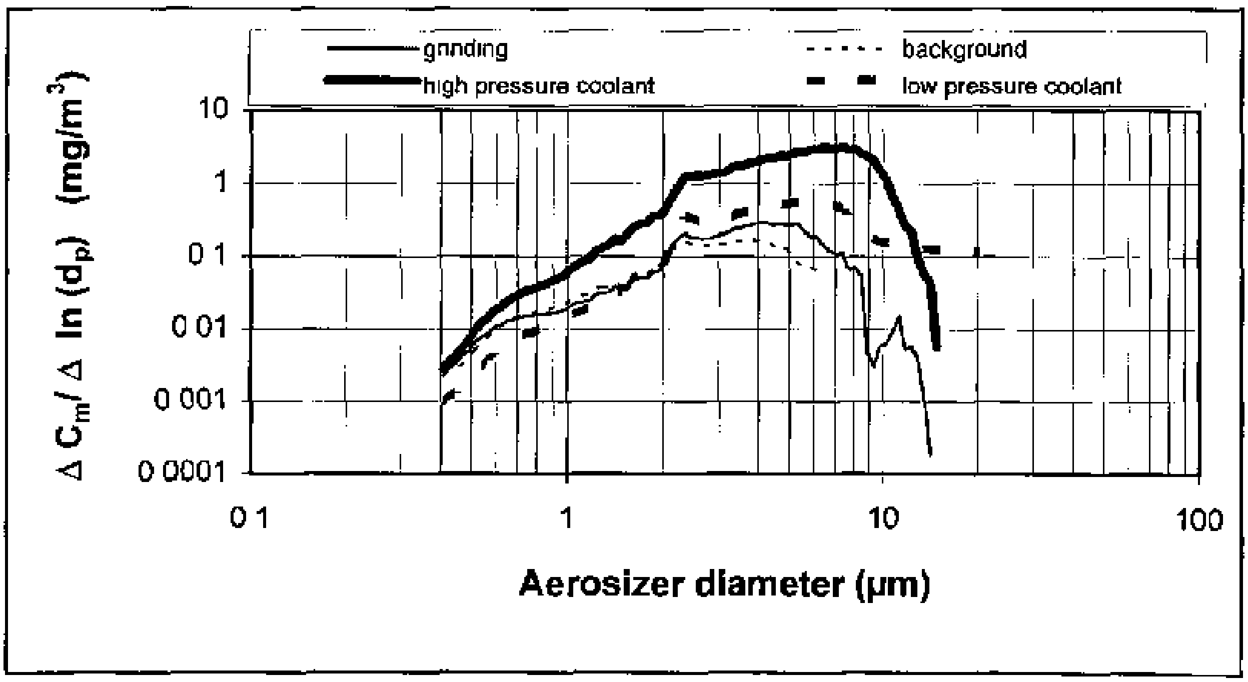

Figure 11 Effect of machining operation upon size-dependent mist concentrations measured by the Aerosizer

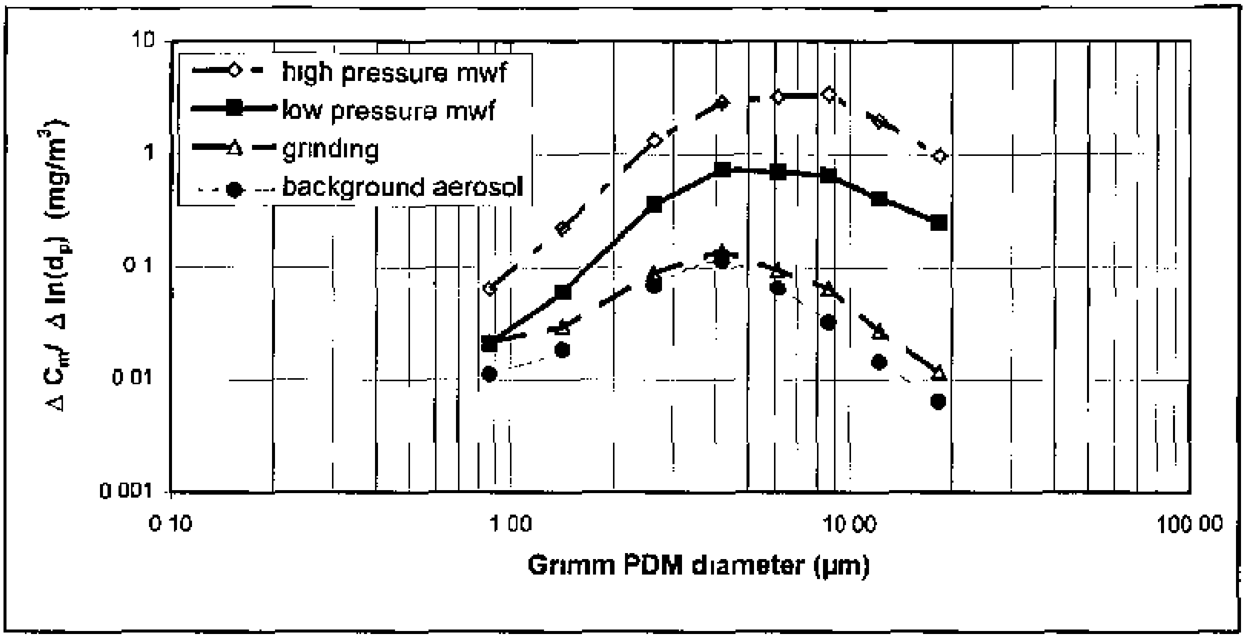

Figure 12 Effect of machining operation upon size-dependent mist concentration measured by the Grimm PDM

difference in the natural logarithms of the particle diameters which is termed "$\Delta \ln(d_p)$ For the QCM impactor, the values of D_{50} presented in Table 1 were used to define the channel widths It must also be noted that the precision of the QCM data is not high, the first sampling stage counted on the order of 30 particles, which were calculated using mass and volume Therefore, there may be statistical fluctuation for this data which must be considered The PDM and the Aerosizer measurements indicated that machining without coolant produced little aerosol, it produced little more than background levels which ranged from 0 1-0 3 mg/m^3

The application of low and high pressure coolant produced an amount of aerosol greater than the background levels of coolant mist In general, the addition of high pressure coolant increased the amount of metalworking fluid mist without affecting the shape of the size distribution In Figure 12, the mass concentration plots for the high and low pressure coolant have different shapes The figure reveals that for particles larger than 10 µm, the mass concentration for the high pressure coolant decreases rapidly However, the plot for the low pressure coolant is essentially a straight line for particles larger than 10 µm The impactor is expected to act as a preselector to drastically reduce the particles larger than 14 µm In addition, the Aerosizer was not consistently measuring larger particles greater than 8-9 µm These differences are probably artifacts due to several phenomena

1 Droplet deformation/breakup caused by the high velocity of 500 m/s in the Aerosizer, causing a smaller apparent diameter This phenomena is presently being investigated by ECTB researchers and further discussion of this phenomena is beyond the scope of this report

2 Liquid drainage from the impactor This liquid may be intermittently dripping off the impaction plate causing erratic measurements

Figures 13-15 compare size distributions measured before the air cleaner to distributions measured at the air cleaners exhaust louvers Each figure contains a weighted average of the concentrations measured upstream of the air cleaner This average was weighted to reflect the fraction of the time that the following machining operations were done while the measurements were made downstream of the air cleaner 1) machining without coolant, 2) applying low pressure coolant, and 3) applying both high and low pressure coolant The ratio of the concentrations measured at the exhaust louvers to this weighted averaged measured upstream of the air cleaner is termed "pseudo penetration" in Figure 16, pseudo penetration is plotted as a function of particle size for the three instruments The results obtained from the Aerosizer indicate that the air cleaner removed everything larger than 4 µm However, the PDM and QCM impactor results indicate that there are particles larger than 4 µm measured in the air flowing out of the air cleaner This discrepancy can be explained by the Aerosizer's correction for the background noise caused by phantom particle creation In this instrument, the number of particles counted is the difference between observed number of particles and a correction for the phantom particles Quite possibly, the counts of few large particles would be lost in the experimental noise attributed to phantom particle creation

The larger particles counted by the Grimm PDM and the QCM impactor are apparently real When one of the authors inspected the exhaust grates of the air cleaner, mist droplets impacted on his glasses Apparently, the liquid pool, which had collected due to the clogged drains, is a source of some mist emissions Clearly, the air discharged from the air cleaner is much cleaner than the background aerosol in the plant by a factor of at least 5 At the outlet of the air cleaner, the estimated aerosol concentrations were 0 01, 0 027, and 0 03 mg/m^3 from the Aerosizer, QCM, and Grimm PDM, respectively When machining operations were not being done, the Aerosizer and the Grimm PDM instruments measured concentrations of 0 3 and 0 14 mg/m^3, respectively Clearly, the air exiting the air cleaner is cleaner than the air in the vicinity of the air cleaner For comparison, Figure 16 shows the efficiencies of the Grimm PDM, Aerosizer, and California Instruments Impactor with respect to measured diameter

EXPERIMENTAL PROCEDURES - PHASE 2

Impinger samples were taken using NIOSH Method 3509 for triethanolamine (TEA) [15] Pump flow rates were increased to 2 lpm The limit of detection (LOD) was 40μg/sample and the limit of quantitation (LOQ) was 130μg/sample There was only one sample that was reported as nondetectable For statistical purposes, this sample was estimated to be LOD/2, or 20μg/sample

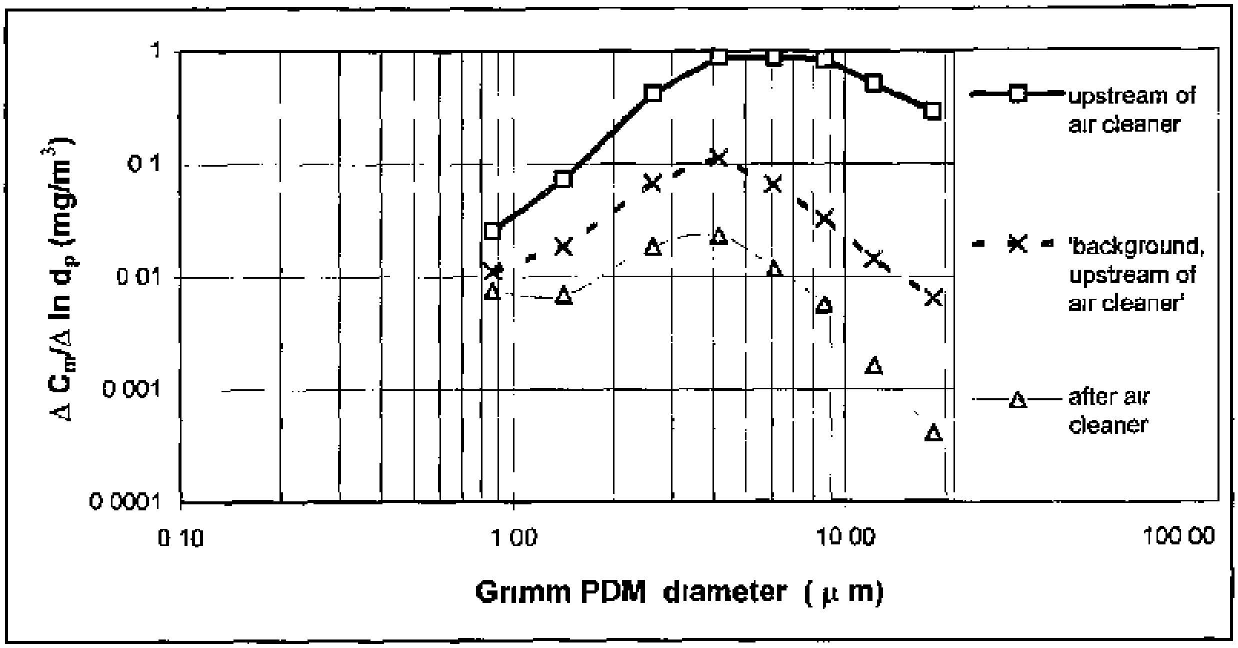

Figure 13 A comparison of mist concentrations upstream and downstream of the air cleaner measured with the Grimm PDM

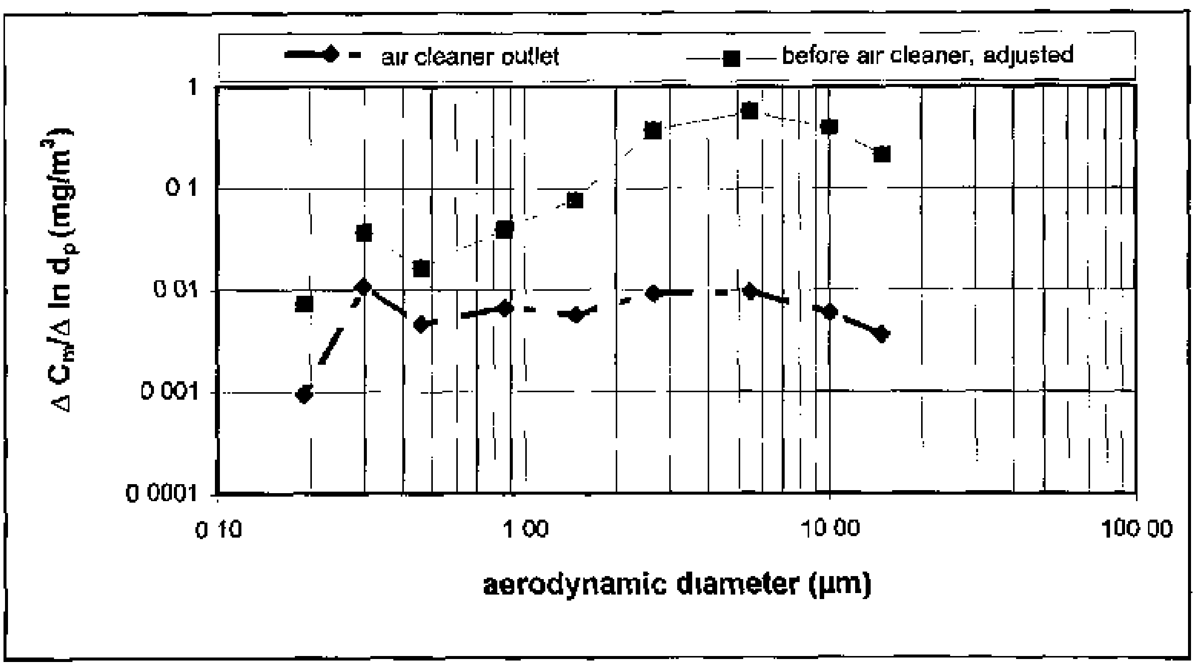

Figure 14 Size-dependent concentrations measured at the air cleaner outlet and before the air cleaner The latter is a weighted average computed so that it has the same fraction of time using the high and low pressure coolant as the measurement at the air cleaner outlet

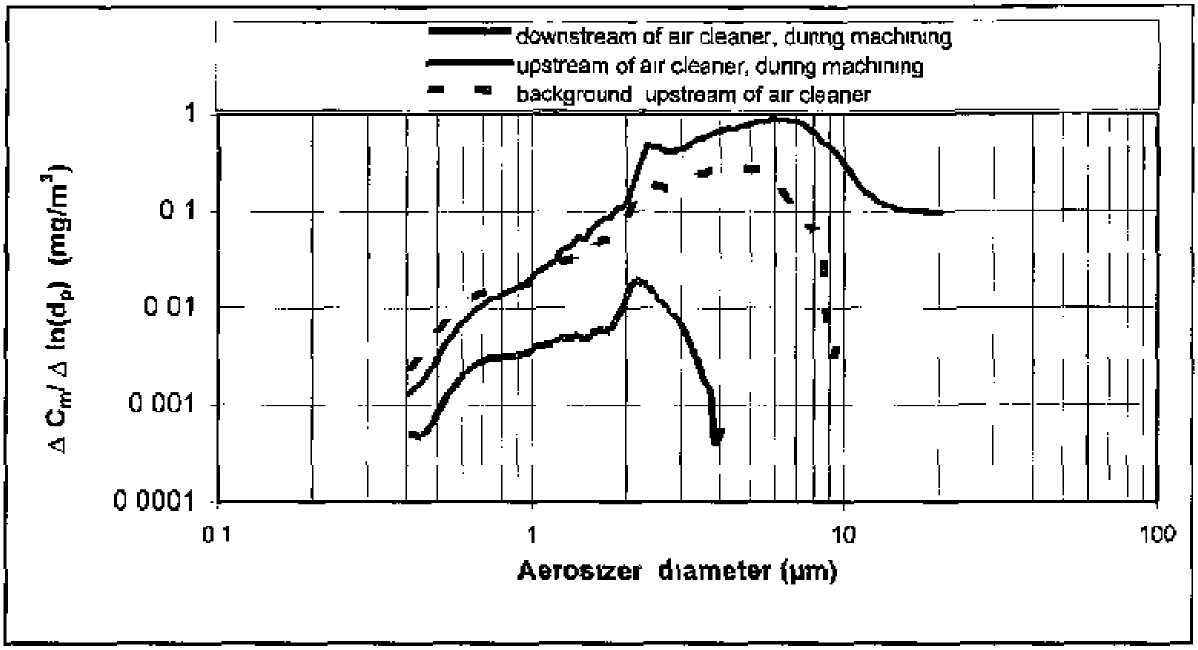

Figure 15 Comparison of size-dependent concentrations measured by the Aerosizer upstream and downstream of the air cleaner

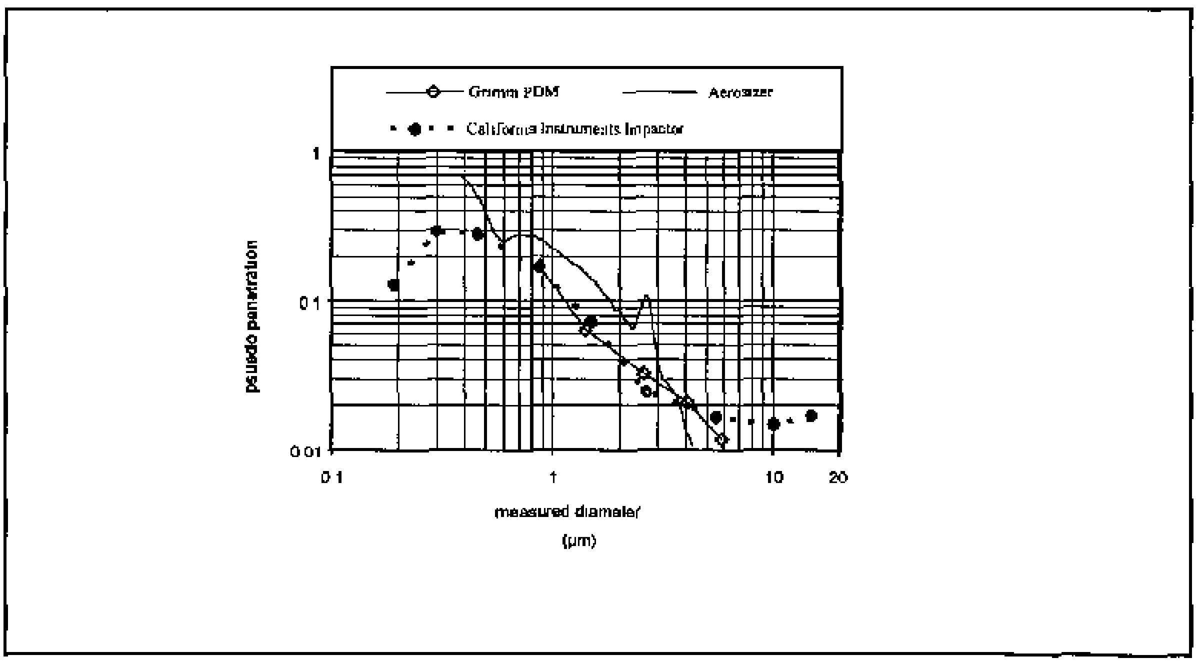

Figure 16 Pseudo penetration through air cleaner as a function of particle size for the Grimm PDM, Aerosizer, and California Instruments Impactor Pseudo penetration is the ratio of the aerosol concentration at the exhaust louvers to a weighted average of the concentration measured upstream of the air cleaner

Samples which were found to be between the LOD and LOQ were estimated with the lab reported result

Impinger sampling was only used for area samples Samples were taken in several areas, including near the air cleaner for both 4 hour and 6 hour periods Two time periods were chosen because the researchers were unsure if the 4 hour samples would have detectable results Two other sites were chosen because they were at opposite boundaries from the L-shop, the samples were denoted as end of L-shop and near the hydromation unit During one period, the reception area, located in the office area of the facility, was sampled in order to obtain a baseline reading Another sample location was denoted as the "problem station" This station was sampled for both TEA and total particulate at the facility management's request This station was the site of worker's many complaints In the past, one worker who had regularly worked at this station had been diagnosed by a physician to have asthma, it is unclear if it was work related This reportedly "problem station" was not located in L-shop, nor was it the same design as the machining station studied, this station was not fully enclosed The worker who normally works at this "problem station" was sampled in his personal breathing zone (PBZ) for total particulate exposure

Personal and area samples for total weight particulate were taken according to NIOSH Method 0500 [15] 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 which resulted in a nondetectable level For statistical purposes, this sample was estimated to be LOD/2, or 0 01 mg/sample

RESULTS AND DISCUSSION - PHASE 2

All results for Phase 2 are shown in Appendix I The impinger data for TEA are summarized in Table 2 The TEA levels measured are well below all levels recommended and mandated The samples located near the hydromation unit revealed the highest levels of TEA, with a geometric mean of 0 43 mg/m^3 There was only one sample (other than blanks) which resulted in nondetectable levels, this sample was taken near the end of L-shop, the sample location furthest from the hydromation unit The samples taken near the end of L-shop were the lowest, with a geometric mean of 0 11 mg/m^3 Statistical analyses were performed on log transformed data [16] Analysis of variance (ANOVA) showed that the sampling location had a significant effect upon concentrations (probability > F < 0 002) Tukey's Studentized Range HSD Test was used to examine the differences between the areas The analyses showed that the difference between the samples taken near the hydromation unit and the other locations were statistically significant at an overall confidence level of 0 05

Table 2: Summary Statistics for Triethanolamine Concentrations

Location	Samples (n)	Average (mg/m^3)	Maximum (mg/m^3)	Minimum (mg/m^3)	Geometric Mean (mg/m^3)	Geometric Standard Deviation
Hydro unit	6	0.45	0.73	0.33	0.43	1.38
End of L-Shop	6	0.17	0.4	0.08	0.11	2.18
Near air cleaner (4 hr samples)	5	0.26	0.35	0.20	0.25	1.34
Near air cleaner (6 hr samples)	6	0.27	0.30	0.24	0.27	1.08

The total particulate concentrations are summarized in Table 3. The total weight particulate measured were well below all mandated limits. As with the TEA results, the highest levels of particulate were found near the hydromation unit, with a geometric mean of 0.48 mg/m^3. The lowest levels of particulate were again found near the end of L-shop, with a geometric mean of 0.08 mg/m^3. Statistical analyses were again performed on log transformed data.[16] Analysis of variance (ANOVA) showed that sampling location had a significant effect upon concentrations (probability > F < 0.0001). Tukey's Studentized Range HSD Test was used to examine the differences between the locations. The analyses showed that the difference between the samples taken near the hydromation unit and the other locations were again statistically significant at an overall confidence level of 0.05.

Table 3: Summary Statistics for Total Particulate Concentrations

Location	Samples (n)	Average (mg/m^3)	Maximum (mg/m^3)	Minimum (mg/m^3)	Geometric Mean (mg/m^3)	Geometric Standard Deviation
Hydro unit	6	0.52	0.86	0.27	0.47	1.57
End of L-Shop	6	0.098	0.24	0.03	0.07	2.17
Personal	17	0.247	0.40	0.09	0.23	1.49
Near air cleaner	6	0.276	0.45	0.13	0.24	1.71

For the "problem station", only one personal sample was taken, this station was operational during only one shift during the period of our visit. The total particulate concentration at this "problem station" was 0.18 mg/m^3. The TEA concentration for the "problem station" was determined to be 0 05 mg/m^3 The worker who normally worked at this station worked elsewhere during the two periods his breathing zone was tested During these periods, his exposures to total particulate were among the lowest of any worker's PBZ samples, with concentrations of 0 08 and 0 14 mg/m^3

Modifications to the Air Cleaner After the Study

During Phase 2 of the study, it was noted that the three air cleaner drains were clogging, perhaps entraining additional mwf mist into the air flow This entrainment was theorized due to mwf occasionally spewing or dripping from the outlet grill of the cleaner As a result, the facility maintenance personnel enlarged the drains from 0 5 inches to 1 inch to allow proper drainage Plastic translucent tubing was added to the drains, leading to a goose neck fitting which led to the hydromation unit The translucent tubing showed if there was fluid draining and would indicate if there was drainage Also, the air cleaner was tilted slightly so that it sloped towards the drains instead of the fans Maintenance personnel reported that the exhaust grill remained clean

Discussion and Conclusions

Phase 1 demonstrated that the air cleaner was effective in reducing the concentration of aerosol It removed most aerosols greater than 4μm, which accounted for 90 percent of the aerosol's mass When the diameter is larger than 4μm, it appears there may be filter penetration Because the mist may contain some water, the aerosol instrumentation may be overestimating the metalworking fluid mist concentration Thus, the aerosol instrumentation is probably overstating the mist concentration and correctly stating the size distribution of the mist However, in selecting air cleaning equipment, the size distribution of the air contaminant is more important consideration In the duct upstream from the air cleaner, concentrations were measured during the low pressure application of coolant to be about 1-2 mg/m^3 During the high pressure application of coolant, this concentration increased to about 2-5 mg/m^3 but with no change in aerosol size distribution The background concentrations of aerosol were about 0 1-0 3 mg/m^3 Downstream from the air cleaner, concentrations were measured at 0 02 - 0 03 mg/m^3 Therefore, the air cleaner is effective at removing aerosol from the air, making it even cleaner than the air in the plant

However, if conditions were to change such that the size distribution of the aerosol were to shift to a smaller size, a HEPA filter may be needed to control the mist emissions from these machines Presently, NIOSH researchers are engaged in a research project dealing with mist generation by machining operations

During the two phases of this study, drainage from the air cleaner was observed to be a problem, causing the air cleaner to become a small but noticeable source of mist emissions As part of a routine maintenance program for these air cleaners, the drainage in the air cleaners needs to be visually checked The preventative maintenance objective is to ensure that the air cleaner does not become a major mist emission source

Phase 2 of the study indicated relatively low concentrations of total particulate and TEA With both substances, the highest concentrations were found near the hydromation unit Perhaps, this unit is causing significant emissions of metalworking fluids into the plant's air In order to reduce mwf mist concentrations throughout the plant, it may be necessary to control this emission source

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APPENDIX I
Mist Concentrations Measured During Various Machining Operations

Mass Concentrations for Various Machining Operations Obtained from Aerosol Instrumentation (mg/m^3)			
Machining Operation	Aerosizer	QCM	Grimm PDM
weighted average before air cleaner	1.12	0.99	2.39
after air cleaner	0.01	0.03	0.03
background (no machining or coolant application	0.32		0.14
grinding	0.20		0.20
low pressure coolant application	0.74	0.82	1.20
high pressure coolant application	3.60	1.80	5.40

Appendix II Triethanolamine Data

Sauer Sundstrand August 1995 Triethanolamine Impinger Data										
Date	Run	Shift	Area	Sample	Time (min)	Pump Vol m3/min	Triethanolamine ug/sample	Triethanolamine mg/m3	Geometric Mean	Geo Std Deviation
8/3/95	6	3	Near cleaner	30	236	0 002	(100)	0 2119	Near cleaner	
8/1/95	1	1	Near cleaner	2	240	0 002	(100)	0 2083	4 hour samples	
8/2/95	3	2	Near cleaner	13	240	0 002	170	0 3542	0 2547	1 34014
8/2/95	2	1	Near cleaner	8	245	0 002	170	0 3469		
8/3/95	4	1	Near cleaner	17	253	0 002	(100)	0 1976		
8/3/95	4	1	Near cleaner	20	328	0 002	200	0 3049	Near cleaner	
8/2/95	3	2	Near cleaner	14	357	0 002	180	0 2521	6 hour samples	
8/1/95	1	1	Near cleaner	5	363	0 002	200	0 2755	0 2690	1 0804
8/3/95	5	2	Near cleaner	23	365	0 002	200	0 2740		
8/2/95	2	1	Near cleaner	10	368	0 002	180	0 2446		
8/3/95	5	2	Near cleaner	25	393	0 002	210	0 2672		
8/1/95	1	1	Hydro unit	3	239	0 002	270	0 5649	Near hydromation unit	
8/2/95	3	2	Hydro unit	11	240	0 002	350	0 7292	0 4342	1 3794
8/3/95	6	3	Hydro unit	28	240	0 002	160	0 3333		
8/2/95	2	1	Hydro unit	7	244	0 002	200	0 4098		
8/3/95	4	1	Hydro unit	19	250	0 002	170	0 3400		
8/3/95	5	2	Hydro unit	24	357	0 002	250	0 3501		
8/1/95	1	1	End L-shop	1	240	0 002	(40)	0 0833	Near end of L-shop	
8/3/95	6	3	End L-shop	31	240	0 002	(40)	0 0833	0 1121	2 1843
8/2/95	3	2	End L-shop	12	242	0 002	ND			
8/2/95	2	1	End L-shop	9	246	0 002	(90)	0 1829		
8/3/95	4	1	End L-shop	18	250	0 002	200	0 4000		
8/3/95	5	2	End L-shop	22	372	0 002	(70)	0 0941		
8/3/95	6	3	Reception	29	350	0 002	ND			
8/3/95	4	1	Problem stn	21	470	0 002	(50)	0 0532		
8/1/95	1	1	Blind Blank	4			ND			
8/1/95	1	1	Blank	6			ND			
8/3/95	6	3	Blank	33			ND			
8/3/95	4	1	Blank	15			ND			
8/3/95	4	1	Blank	16			ND			
8/3/95	5	2	Blank	26			ND			
8/3/95	5	2	Blank	27			ND			
8/3/95	6	3	Blank	32			ND			

LOD = 40 ug/sample
LOQ = 130 ug/sample
( ) Parameter between LOD and LOQ

Appendix III Total Particulate Data

Total Particulate Data										
				Filter	Time	Sample	Conc	Average	Geometric	Geo Std
Date	Run	Shift	Area	Number	Hr min	(mg)	(mg/m3)	(mg/m3)	Mean	Deviation
8/3/95	4	1	Worker 9	1966	6 37	0 54	0 340		Personals	
8/3/95	4	1	Worker 8	1967	7 00	0 68	0 405	0 240	0 230	1 498
8/2/95	3	2	Worker 7	1959	5 46	0 33	0 238			
8/3/95	5	2	Worker 6	1961	5 48	0 53	0 381			
8/2/95	2	1	Worker 6	1969	5 53	0 52	0 368			
8/3/95	6	3	Worker 5	1945	1 34	ND				
8/3/95	4	1	Worker 5	1953	6 48	0 43	0 263			
8/2/95	2	1	Worker 5	1979	6 07	0 4	0 272			
8/2/95	2	1	Worker 4	1986	5 55	0 33	0 232			
8/3/95	6	3	Worker 3	1947	5 54	0 36	0 254			
8/2/95	3	2	Worker 3	1952	5 44	0 35	0 254			
8/1/95	1	1	Worker 3	1983	5 57	0 23	0 161			
8/1/95	1	1	Worker 2	1990	5 54	0 26	0 184			
8/3/95	5	2	Worker 12	1964	4 54	0 26	0 221			
8/3/95	5	2	Worker 11	1963	3 41	0 26	0 294			
8/3/95	4	1	Worker 10	1954	6 43	0 23	0 143			
8/2/95	2	1	Worker 10	1989	6 07	0 12	0 082			
8/2/95	3	2	Worker 1	1971	5 53	0 13	0 092			
8/1/95	1	1	Worker 1	1984	5 51	0 19	0 135			
8/3/95	6	3	Near cleaner	1949	5 57	0 18	0 126		Near cleaner	
8/3/95	5	2	Near cleaner	1951	5 58	0 64	0 447	0 276	0 246	1 713
8/3/95	4	1	Near cleaner	1956	5 29	0 5	0 380			
8/2/95	3	2	Near cleaner	1981	6 00	0 25	0 174			
8/2/95	2	1	Near cleaner	1958	6 08	0 55	0 374			
8/1/95	1	1	Near cleaner	1985	6 03	0 23	0 158			
8/3/95	6	3	Hydro unit	1948	6 14	0 4	0 267		Hydro unit	
8/3/95	5	2	Hydro unit	1962	5 56	0 94	0 660	0 519	0 478	1 577
8/3/95	4	1	Hydro unit	1974	5 32	0 38	0 286			
8/2/95	3	2	Hydro unit	1980	6 00	1 24	0 861			
8/2/95	2	1	Hydro unit	1970	6 13	0 76	0 509			
8/1/95	1	1	Hydro unit	1975	6 02	0 77	0 532			
8/3/95	6	3	End L-Shop	1950	5 59	0 11	0 077		End L-Shop	
8/3/95	5	2	End L-Shop	1968	5 33	0 08	0 060	0 096	0 760	2 178
8/3/95	4	1	End L-Shop	1955	5 28	0 31	0 236			
8/2/95	3	2	End L-Shop	1972	6 00	0 06	0 042			
8/2/95	2	1	End L-Shop	1976	6 07	0 2	0 136			
8/1/95	1	1	End L-Shop	1988	6 04	0 04	0 027			
8/3/95	5	2	Blind Blank	1943	0 00	ND				
8/1/95	1	1	Blind Blank	1960	0 00	ND				
8/1/95	1	1	Blind Blank	1978	0 00	ND				
8/1/95	1	1	Blank	1977	0 00	ND				
	6	3	Reception	1965	6 57	0 05	0 030			
	4	1	Problem Stn	1957	7 50	0 34	0 181			