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Metalworking Fluids: Oil Mist and Beyond

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This article is based upon my own experiences with metalworking fluids and the adverse health effects and medical conditions associated with exposure to metalworking fluids. I have researched and witnessed the benefits that can be achieved when metalworking fluids are properly maintained and managed. My experiences have provided insight into how a shop operates, including comprehension of the equipment used, processes, mist generating points, engineering controls currently being adopted, and procedures that are used to maintain metalworking fluids. I have been able to share my personal experiences with the country's leading experts in the field of metalworking fluids.

I have presented my insights on the topic in Washington, D.C., to the Standard Advisory Committee of OSHA, as well as at many other conferences nationwide. I have provided awareness training for a number of union and nonunion workers. Being a part of developing successful metal removal fluid programs, I realize the importance of transferring and sharing information. Many times an organization is not fully aware of certain conditions and how to combat them. My mission and intent is to properly educate those who are exposed to the harm that metalworking fluids can invoke and to inform those involved of the possible methods of reducing long- and short-term risk.

One thing that must be kept in mind is the way we view these fluids. Many shops categorize the fluids as a type of "operating expense" when they should actually be seen as a sort of investment. Just as performing a scheduled maintenance on a machine promises the best possible longevity of that machine, the upkeep of metalworking fluid also provides longer "tool life." Monitoring and maintaining the fluids also provides for more effective and efficient productivity. If we fail to consider that proper management of the fluids can cut cost dramatically, then we will miss out on the financial impact they can have on a company.

Try looking at the fluids as a liquid tool. Doing so I believe will bring a better understanding of the value of a successful metalworking fluids program.

With this new understanding, it can be seen just who must play a role in the management of metalworking fluids. The employees who deal with the daily tasks involving the coolant play a major part. They are on the floor where these metalworking fluids are being used. In many shops, it is assumed that the environmental health & safety departments are responsible for standard operating procedures and management of fluids. The EH&S department should only be responsible for the protection from exposure and the transfer of information regarding policy and procedure to their employees. Not all shops have the resources required to develop and implement the proper standard operating procedure. Therefore, we must understand that what is feasible for one may not be for another. Companies that lack the sufficient resources should not be neglected. It is crucial that awareness of proper standard operating procedure is shared with everyone involved with the fluids in order to provide proper metalworking fluids management. Fluids are as dynamic as the formulations themselves (complex & dynamic). These fluids can quickly become contaminated with foreign materials and chemicals, thereby become aerosolized into mist. With proper education and training, one will be able to control what gets aerosolized.

Keywords Hazards associated with metalworking fluids

END USER'S PERSPECTIVE

Machinists are usually well aware of the safety hazards associated with operating machines. Less known, however, are the health hazards associated with the use of metalworking fluids.

BACKGROUND

Metalworking fluids are liquids used in the machining process for cutting, turning, grinding, boring, drilling, hobbing, broaching, and other tasks. Their purpose is to provide lubricity in order to remove friction and control thermal distortion by carrying away the heat, thereby improving the machinability. At

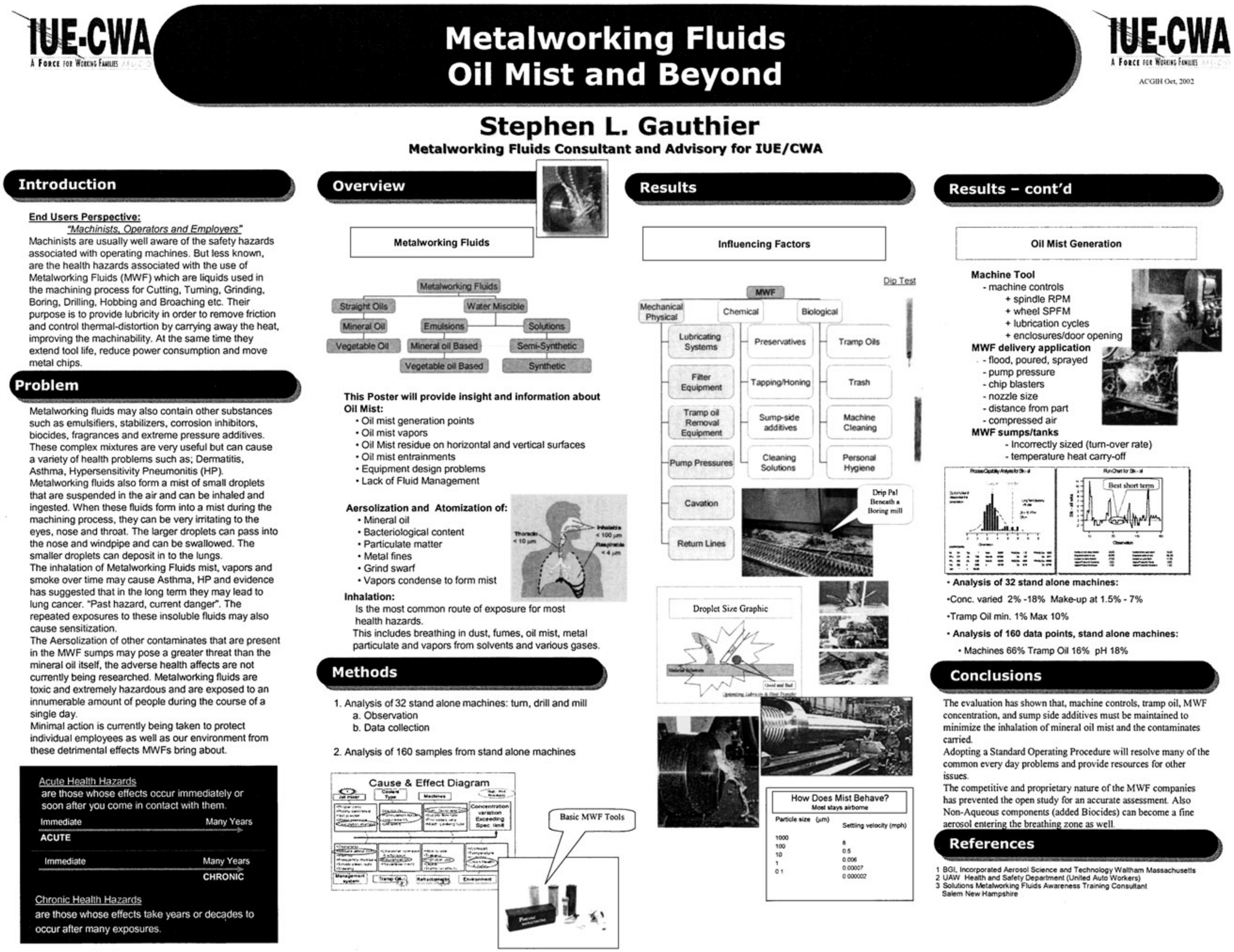

FIGURE 1

Poster presented at the ACGIH "*Health Effects of Mineral Oil Mist and Metalwroking Fluids Symposium*," October 2–4, 2002, Cincinnati, Ohio.

the same time, they extend tool life, reduce power consumption, and remove metal chips.

Metalworking fluids may contain other substances such as emulsifiers, stabilizers, corrosion inhibitors, biocides, fragrances, extreme pressure additives, and contaminants. These complex mixtures are very useful but can cause a variety of health problems such as dermatitis, asthma, and hypersensitivity pneumonitis (HP).

Metalworking fluids can form a mist of small droplets that are suspended in the air and can be inhaled and ingested. When these fluids form into a mist during the machining process, they can be very irritating to the eyes, nose, and throat. The larger droplets can pass into the nose and windpipe and can be swallowed. The smaller droplets can deposit into the lungs.

The inhalation of metalworking fluids mist, vapors, and smoke over a period of time may cause asthma or hypersensitivity pneumonitis, and evidence has suggested that they may lead to lung cancer. The repeated exposures to these insoluble fluids may also cause sensitization at different degrees.

The aersolization of other contaminants that are present in the metalworking fluid sumps may pose a greater threat than the mineral oil itself. These adverse health affects are currently being researched. Metalworking fluids are toxic and extremely hazardous and are exposed to an innumerable amount of people during the course of a single day.

Minimal action is currently being taken to protect individual employees as well as our environment from the detrimental effects of metalworking fluids.

Acute Health Hazards

Acute health effects are caused by sudden and severe exposure and rapid absorption of the substance. Normally, a single large exposure is involved. Acute health effects are often reversible.

Chronic Health Hazards

Chronic hazards are those whose effects take years or decades to occur after many exposures. Chronic health effects are caused by prolonged or repeated exposures over many days, months, or years. Symptoms may not be immediately apparent. Chronic health effects are often irreversible.

OVERVIEW

Metalworking Fluids

There are four basic classifications of metalworking fluids that can be applied. Depending on the specifics of the application, any one of the four could be used successfully. The four classifications are insoluble oil, soluble metalworking fluids, synthetic metalworking fluids, and semi-synthetic metalworking fluids.

Insoluble Oils

These formulations contain no water and are comprised of neat oil. Frequently referred to as cutting oils, insoluble oils are used as lubricants. They improve the finish on the metal cut and prevent rusting. The petroleum oils used in insoluble metalworking fluids are usually refined mineral oils. Animal, marine, or vegetable oils may also be used singly or in combination with mineral oils to increase wetting action and lubricity. Insoluble oils are used for moderate- to heavy-duty machining and require fewer additives than the soluble types.

Soluble Metalworking Fluids

These emulsions and water-soluble oils are designed to cool and lubricate. These fluids prevent welding of the cutting tool and the work surface, reduce abrasive wear of the tool at high temperatures, and prevent thermal distortion caused by residual heat. The highly refined mineral oils of soluble metalworking fluids are blended from higher viscosity oil bases than are insoluble oils. Soluble metalworking fluids concentrates are diluted with water at different ratios before use and contain a surface-active emulsifying agent to maintain the oil-water mix in an emulsified oil and water phase.

Synthetic Metalworking Fluids

Synthetic metalworking fluids do not contain oil; the simplest synthetics are composed of organic and inorganic salts dissolved in water. Also functioning as coolants and lubricants, synthetic metalworking fluids eliminate smoking, reduce misting, provide detergent action, and reduce oxidation. Consequently, the simple synthetics offer rust protection and good heat removal, but usually have very low lubricating ability. Synthetics are stable, can be supplemented with biocides to discourage the growth of microorganisms, and provide effective cooling capacity at high machining speeds and feed rates.

Semi-Synthetic Metalworking Fluids

This class of metalworking fluids contains small amounts of oil (5% to 30% in the concentrate) and may be formulated with fatty acids, sulfur, chlorine, and phosphorous to provide lubrication for higher speed and feed operations to medium and heavy operations. The same extreme-pressure agents that are added to insoluble oils may also be added to water-soluble oils. Coupling agents are used to maintain emulsification. Antifoaming agents, dyes, perfumes, and water softeners may also be added. Biocides may be added to reduce the growth of bacteria and fungi in water-based fluids.

The presence of water in the soluble fluids can cause machine tools and parts to corrode. Consequently, nitrites, amines, and certain oils may be added to inhibit corrosion. No matter which type of metalworking fluid is used, the aerosolization of contaminants still occurs. The better the understanding of how mists are generated and what is being aerosolized within them, the greater the ability to control and minimize the ill affects from exposure.

INFORMATION ABOUT OIL MIST

The following paragraphs provide a practical end user's perspective of oil mist.

Oil Mist

The aersolization and atomization of mineral oil, bacteriological content, particulate matter, metal fines, and grind swarf pose a much greater threat than once believed. Inhalation is the most common route of exposure for most health hazards. This also includes not only oil mist, but also breathing in dust, fumes, and vapors from solvents and various gases.

The mists are the results of fluid tool interaction. Oil mist and the source generation points are critical when evaluating a process of exposure control. Once identified, feasible engineering controls should be evaluated and adopted. The engineering controls must be tracked for effectiveness and adjusted as necessary.

Droplet Size

Droplet size (water and oil phase of an emulation) and its effect on oil mist are affected by many factors. Contaminants that are in the sumps are emulsified and passed through the delivery system to the cutting tool. By allowing the emulsification of tramp oil and other contaminants by continuous pumping, is passed to the cutting zone causing smoke and vapors, etc. The emulsification of these contaminants poses an unknown oil mist health hazard.

Vapors

During the machining process, a considerable amount of heat is generated at the cutting zone and may produce vapors resulting from the heating of the metalworking fluids. The vapor then is produced as a result of boiling. Vapor generated then may condense to form mist.

Oil Mist Residue

The significance of oil mist residue is that it accumulates on horizontal and vertical surfaces caused by the machining process. The residues are key identifiers associated with the lack of good ventilation controls. Using close capture techniques allows for minimum cubic feet per minute (CFM) requirements. Further evaluation may reveal that the metalworking fluid concentration level may be higher than recommended. Tramp oil may also affect residue by emulsification and entrainment.

Oil Mist Entrainments

Contaminants become entrained in the oil mist and are identified as any substance that is not part of the original metalworking fluid formulation. Examples are machine paints that have peeled from the inside of tank surfaces, metal fines from chip generation, and grinding swarf operations, lubricating oils, and personal hygiene.

Equipment Design

Attention to the details when designing the equipment is essential. Equipment design often creates problems that limit the ability to minimize the misting by not being able to remove contaminants. These problems may occur from improper tank sizing allowing inadequate retention time, which reduces the ability to separate tramp oil and allows metal fines and grind swarf to settle. Tanks or sumps with square corners allow sludge to accumulate. Return sluice-ways allow stagnation to occur and promote biological growth that may become entrained in the aerosol generated by the process.

Oil Mist Generation

Oil mist generation is controllable either by changing the ladder parameters within the machines control or installing a PLC (programmable logic control) to allow control over start/stop cycles. These cycles are spindle revolutions per minute (RPM), wheel surface feet per minute (SFPM), lubrication cycles, and enclosures door opening cycles.

Delivery Application

The delivery application affects the generation of mist. The method may be flood, poured, or sprayed. The mist levels are affected by the pump pressure, chip blasters, nozzle size, distance from part, and compressed air used to clean parts covered with metalworking fluid.

EVALUATION METHOD

An evaluation was conducted to determine the need for a standard operating procedure as part of a fluids management program, using the method and laboratory analysis outlined in Tables I and II.

There were evaluations of two shops: The first shop evaluation included an analysis of samples of the metalworking fluids from 32 stand-alone machines (turn, drill, and mill) using observation and data collection; The second shop evaluation included analysis of samples from 160 stand-alone machines. Using standard testing methods for evaluation were shop floor and laboratory comparing variation.

Cause and Effect

After gathering samples and data a cause and effect evaluation of the management of the metalworking fluids was conducted. Data results are shown in Tables III and IV. There were seven categories used to identify the most significant causes contributing to the variation in the management process.

TABLE I
Shop floor method

Refractometer	Verifiable range based upon recommendations
pH	Test strips (pH 5–10 range)
Hardness	Test strips (graduations 0/5/10/15/20/25 °d)
Tramp oil	100-ml bottle allowed sitting 24-hr measuring top layer to determine %.
Free oil	Total oil not emulsified allowed to separate

TABLE II
Laboratory analysis

Appearance of the emulsion	Visual
Color of emulsion	Visual
Odor	Smell
Oil separation	Gravimetric
Concentration	Manufacturer recommendation
Refractometric	Refractometer (range 0–32°); Minimum division 0.2°
Acid split	Split into two phases (water/oil)
pH value	Test strips (pH 5–10 range)
Potentiometric	pH meter
pH indicator paper	Test strips (pH 5–10 range)
Hardness of emulsion	Test strips (graduations 0/5/10/15/20/25 °d)
Corrosive behavior	TM 403
Particle size determination	Nanosizer
Specific conductivity	Conductivity meter

The cause and effects categories were mixing, fluid type, machine tool, management system, tramp oil, droplet size, refractometer, and the environment.

Mixing

The analysis included mixing, proportional device, concentration, refractometer calibration, water pressure, and calculation methods. It was found that improper calculation methods, causing an over-concentrated condition, were a contributing factor to the variation. The most effective way to assure accurate mixing would be the use of standard operating procedures.

Fluid Type

The analysis included formulation, concentration of fluids, pH level, dirt load, and microbial contamination. It was found that metalworking fluid types have requirements that vary. The parameters and frequencies have an impact on the composition of the mist generated at the tool interface. Formulation was found to be a contributing factor to the variation. Proper parameters and frequencies must be maintained.

TABLE IV
Metalworking fluids: How mist behaved

Particle size (μm)	Settling velocity[A] (MPH)
1000	8
100	0.5
10	0.006
1	0.00007
0.1	0.000002

[A]The settling velocity (weight measurements in micron scale) is a calculation for unit density spheres—oil mist would have lower density, but settling velocity would be close.

Machine Tool

The analysis included evaluation of the turn, grind, and drill operations. It was found that the different machine tools had varying degrees of aerosols generated caused by the process. The volume GPM (gallons per minute) of fluid being delivered to the tool and the speed (RPM revolutions per minute) the tool or part is rotating had impact on the mist generation. The machine lubricating defects (leaks) were found to be a contributing factor to the variation. An effective PM program would be an effective way to minimize leaks.

Management System

The analysis included evaluation of the frequency of measurements, methods to be used, scheduled machine clean-outs, training programs, and the attitude about metalworking fluids and ownership (or who owns the responsibilities). Attitude was found to be a contributing factor to the variation. In addition, there was no understanding about control techniques and options available. Education and training would be effective ways of improving attitudes.

Tramp Oil

The analysis included tramp oil composition; contributing sources such as machine lubricating and hydraulic systems, petroleum-based preservatives, and other types of lubricants; emulsification; oil removal; and preventive maintenance. It was found that these oils were becoming emulsified and entrained,

TABLE III
Metalworking fluids: Influencing factors

Mechanical/physical	Chemicals	Biological
Lubricating systems	Cleaning solutions	Tramp oils (food source)
Tramp oil removal equipment	Preservative	Trash
Pump cavation (air bound)	Tapping and honing oils	Machine cleaning
Filter equipment	Sump-side additives	Personal hygiene
Pump pressures		
Return lines/sluice-ways		

becoming part of the aerosols and mists generated. It was also found that the most effective way to deal with tramp oils is to remove them using one of the many different types of equipment. This will limit the amount that will become emulsified and passed to the cutting tool. Machine lubricating and hydraulic systems leaks were found to be a contributing factor to the variation.

Preventive maintenance would be an effective way to assure machine performance and to minimize the contributing factors of machine lubricating and hydraulic systems leaks. Revisiting the process to further evaluate the efficiency of the equipment is also recommended.

Refractometer

The analysis included proper use of the refractometer. It was found that operators were not being trained as to the type and scale value to be used and how to deal with tramp oil. The tramp oil altered the readings that are obtained by the user. Improper use of the refractometer was found to be a contributing factor to the variation.

Proper training will minimize the potential for an over-concentrated system.

Environment

The analysis included housekeeping, temperature, formulation, humidity, personal hygiene, and workload. It was found that housekeeping contributed a number of contaminants to the fluids. Housekeeping is an important control to prevent operators from coming in contact with metalworking fluids and other potential hazards such as dirt, debris, and floor cleaning chemicals. Housekeeping was found to be a contributing factor to the variation. Realizing housekeeping is an issue that affects metalworking fluids can help.

EVALUATION RESULTS

Process Capabilities

Results were achieved by taking collected data and using statistical tools to evaluate the data. It was found that the lower specification limit set point showed that the larger majority of the metalworking fluids concentration levels fell below the recommended lower specification, causing pH level, rust, bacteria, and fungi due to lack of make-up boosters.

Results were obtained using Run-Data taking the best short-term data. These were reviewed for differences in control practices. Results showed that upper specification and lower specification were achievable by the control of the concentration.

Analysis of 32 Data Points from Stand-Alone Machines

The analysis of 32 stand-alone machines found that the concentration of the metalworking fluids varied between 2 percent to 18 percent because of the lack of system control. The evaporation make-up process result was 1.5 percent to 7 percent. This raises several issues. Make-up at the 1.5 percent level may not allow the proper boosters to be added, causing product and health issues.

The tramp oil minimum was 1 percent and the maximum was 10 percent. The level above 2 percent could cause health issues due to emulsification.

Analysis of 160 Data Points from Stand-Alone Machines

In this second set of data, the findings were similar. The contributing factors were found to be that the machines contributed 66 percent because of lack of machine maintenance and leaking lubrication systems. Tramp oil contributed 16 percent because they were not being removed. The pH contributed 18 percent because of tramp oils and lack of concentration control.

CONCLUSIONS

The competitive and proprietary nature of the metalworking fluids companies has prevented the open study for an accurate assessment.

The lack of a fluids management program has contributed an estimated 80 percent (Technical Service laboratory) toward potentially increasing the health exposure risk associated with the metalworking fluid oil mist. This shows the need for an effective metalworking fluids program. A successful metalworking fluids program will consist of a comprehensive and well-understood written standard operating procedure (SOP) for all aspects of the intended program. The program should include proper training, implementation guidelines, preventive maintenance procedures, and follow-up. The fluid supplier and manufacturers guidelines will also be needed in this effort. This is a proactive approach rather than a reactive one.

Process variability, and the lack of systematic operational procedure has shown that machine controls, tramp oil, metalworking fluids concentration, and sump side additives must be maintained to minimize the inhalation of mineral oil mist and the contaminants carried. The machines also should be broken down and cleaned at least once each year. A regular and systematic written procedure for cleaning of the sump and coolant should be completed and included in the standard operating procedure.

Adopting a standard operating procedure will resolve many of the common problems. It is becoming more important every year to go beyond existing regulations and requirements. Innovators who reduce manufacturing's impact on health, safety, and the environment because of metalworking fluids are sure to stand out from those who simply follow the regulation requirement.

Finally, assumption should never be the process evaluator.

REFERENCES

There are guidelines available for starting a metalworking fluid program, including the following:

- ORC: *Metal Removal Fluids: A Guide to Their Management and Control*
- NIOSH: *Criteria Document*
- OSHA: *MWF Best Practices Manual*
- AAMA *Proceedings*
- Ventilation guidelines:
  - *Industrial Ventilation: A Manual of Recommended Practice* (ACGIH)
  - *Mist Control Considerations for the Design, Installation, and Use of Machine Tools Using Metalworking Fluids* (ANSI)

APPENDIX A

MWF History:

- 1977 NIOSH "Cutting Fluids" Criteria Document proposal
- 1993 UAW petitions OSHA for ETS
- 1995, 1997 AAMA Symposia
- 1997 ANSI Mist Control Standard
- 1997 UAW-Chrysler HP Workshop
- 1998 NIOSH Criteria Document
- 1999 OSHA SAC report
- 2001 OSHA MWF *Best Practices Manual*