
17 Health and Safety Aspects in the Use of Metalworking Fluids

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CONTENTS

17.1	Introduction	411
17.2	Routes of Chemical Exposures	413
17.3	Machining Environment and Health	414
17.4	Health Effects Associated with MWF Exposures	415
17.4.1	Dermatological Conditions	415
17.4.2	Respiratory Conditions	416
17.4.3	Carcinogenicity of MWF Materials	418
17.5	Historical Notes of MWF Stakeholder Activities to Promote Health and Safety	419
17.5.1	OSHA MWF Standards Advisory Committee	420
17.5.2	Organization Resources Counselors	420
17.5.3	MWF Symposiums	421
17.6	Conclusion	422
	References	422

17.1 INTRODUCTION

Industrial operations that utilize metalworking fluids (MWFs) may expose some workers to a variety of conditions or substances that present hazards that can affect their health and safety, depending on the nature of specific work activities or conditions in machine shops. Especially under conditions where there are prolonged and relatively high concentrations of inimical exposures, workers may experience respiratory and skin problems to various degrees of severity. In general, machining hazards while utilizing MWFs may be classified into three broad categories:

- *Physical:* Abrasions, cuts or skin damage due to contact with metal fines or swarf; accidental bodily contact with moving machine components, metal sharps, and so on
- *Chemical:* Inhalational or dermal contact with chemical constituents in MWF formulations or contaminants that result in respiratory illnesses or dermatological disease(s)
- *Biological:* Inhalational or dermal contact with microbiological constituents that proliferate in MWF formulations that cause respiratory illnesses or some dermatologic disease conditions

According to the U.S. Occupational Safety and Health Administration (OSHA),

Metalworking fluids can cause adverse health effects through skin contact with contaminated materials, spray, or mist and through inhalation from breathing MWF mist or aerosol. Millions of workers engaged in the manufacture of automobiles, farm equipment, aircraft, heavy machinery, and other hardware are exposed to machining fluids.¹

OSHA published a best practices manual in 2001 that addressed a variety of health effects in machining operations.²

A comprehensive study reported in a criteria document prepared by the National Institute for Occupational Safety and Health (NIOSH) stated that approximately 1.2 million workers are annually exposed to metalworking fluids.³ As part of this comprehensive publication, NIOSH recommended an occupational exposure limit (REL) of

0.4 mg/m³ of air (thoracic particulate mass) (portion of MWF aerosol that penetrates beyond the larynx) as a time-weighted average (TWA) concentration for up to 10 hr/day during a 40-hr work week, measured according to NIOSH Method 0500. The 0.4 mg/m³ concentration corresponds to approximately 0.5 mg/m³ for total particulate mass.

In part, elements of the NIOSH criteria document recommended a number of measures to protect MWF workers.

- Informing workers about the hazards
 - Safety and health training
 - Hazard prevention and control
- Engineering controls and work practices
 - MWF selection
 - Fluid use and delivery
 - Fluid maintenance
 - Ventilation systems
 - Protective clothing and equipment (personal protective equipment [PPE])
- Respiratory protection
- Sanitation and hygiene
- Medical monitoring
- Labeling and posting

Occupational safety and health specialists, especially industrial hygienists, utilize a variety of measures to prevent, recognize, evaluate, and control hazards in the workplace.

- Engineering controls
 - Process and facility design
 - Machine enclosures
 - Machine guarding, shields, and barriers
 - Ventilation
 - Exhaust ventilation systems
 - Machine enclosures
 - Close capture (at point of operation)
 - Total (entire machine)
 - Tunnel (over several machines)
 - Mist collectors
 - Material substitution
- Administrative controls
 - Employee training
 - Work practices
 - Hazard recognition
 - Task scheduling
- PPE
 - Respirators
 - Proper selection
 - Fit testing
 - Usage scenarios

- Eye protection
- Hearing protection
- Protective clothing, gloves (impervious)

Regardless of the extent and effectiveness of exposure controls, some workers experience health and safety problems as a result of exposures to both known and unknown agents and conditions in the workplace. There are some diagnoses of illnesses among machinists that may be inconclusive or deemed idiopathic, due to multifactorial exposures in workplace environments that are not fully identified or understood, and individual susceptibilities may present confounding factors. Depending on the type and extent of exposures to chemicals, susceptible individuals may experience health problems related to the toxicologic, mutagenic, and carcinogenic properties of some chemicals or contaminants in chemicals.

Technologies and strategies for controlling and protecting workers against MWF exposures are constantly evolving, and many federal, academic, industry, and union-funded research programs are underway. However, many MWF formulations are complex proprietary chemical mixtures that are not easily characterized for purposes of toxicologic and epidemiologic studies.⁴ Also, there can be chemical interactions among constituents in MWF mixtures that recombine *in situ* to form secondary and tertiary reaction products.

17.2 ROUTES OF CHEMICAL EXPOSURES

As shown in Table 17.1, industrial chemicals can enter the body by various routes—that is, skin absorption, inhalation, and ingestion.

Exposures to some chemicals in the workplace may be problematic because many molecules exert their damaging effects at the cellular level and there may be a period of latency prior to the manifestation and diagnosis of illnesses. Occupational diseases and functional disorders caused by chemicals commonly exhibit classical dose–response or exposure–response relationships. Adverse physiological effects initiated by chemical exposures may be acute (appearing shortly after exposure) or chronic (long lasting or constantly recurring), depending on a variety of factors:

- Route of exposure
- Duration of exposure
- Type of chemical or contaminant
- Concentration of chemical or contaminant
- Susceptibility of a worker to chemical or contaminant
- Interactions of chemicals and contaminants in a mixed exposure

Owing to the multiplicity of mixed chemical exposures encountered in any given workplace environment, especially via the airborne route, a positive identification of the etiologic agent(s) of

TABLE 17.1
Routes of Chemical Exposures

Exposure Route	Facilitators	Potential Health Effects	Comments
Skin absorption	Dermal permeability, damaged skin, prolonged exposure	Contact dermatitis, allergic dermatitis	Skin sensitization to certain chemicals in some individuals
Inhalation	Respirable and inhalable aerosols (1–5 μm), vapors, particulates	Upper respiratory tract irritation, pulmonary diseases	Most common exposure route
Ingestion	Accidental swallowing	Mouth, pharyngeal, esophageal damage, digestive tract disorders	Minor exposure

an occupational disease and its source(s) may not be easily discerned, as noted earlier. Traditionally, one of the most often recommended industrial hygiene measures to protect worker health is to enhance local and area ventilation turnover rates in workplaces.

17.3 MACHINING ENVIRONMENT AND HEALTH

Metal removal fluids (MRFs) are a subset of the broader group of industrial products known as MWFs, which include industrial cleaners, metal forming and stamping fluids, corrosion preventives, and heat-treating fluids, as well as metal removal fluids.

Facilities that utilize MWFs range from small shops with a few workers to sprawling industrial complexes that cover many acres with hundreds of employees during any given work shift.^{5,6} Regardless of the size of the facility, routine occupational activities can produce a variety of exposure hazards, which mainly consist of airborne emissions from industrial processes, aerosols, diesel exhausts, fugitive dusts, vapors, and particulates.

As MWFs circulate through individual sumps and large central systems, they may undergo chemical, physical, and biological changes over time that affect their compositions.

- Constituents and additives deplete.
- Metal fines and swarf accumulate.
- Dirt, dust, and shop debris accumulate.
- Tramp oils, hydraulic fluids, way oils, and other exogenous lubricants accumulate.
- Mists increase.
- Microbes proliferate (in water-based products).
- Organic acids accumulate.
- pH fluctuates.
- Alkalinity changes.
- Hard water salts increase.
- Emulsions break.
- Foam increases.

Changes in the composition of used MWFs can affect the health of workers in various ways, as shown in Table 17.2.

TABLE 17.2
Potential Health Effects Caused by Physical, Chemical, and/or Biological Changes in MWFs

Physical	Chemical	Biological
Dirt buildup (respiratory irritation↑)	Depletion of effective biocide concentration (microbial growth↑)	Uncontrolled bacterial growth (respiratory irritation↑, aesthetic acceptability↓)
Increase in tramp oil content (unemulsified) (mists↑, respiratory exposures↑, dermatitis↑)	Excessive biocide addition (sensory and respiratory irritation↑, skin irritation↑)	Uncontrolled fungal growth (respiratory irritation↑, aesthetic acceptability↓)
Metal fines buildup (skin abrasions↑)	Nitrosamine production (carcinogenesis potential↑)	Endotoxin buildup (respiratory irritation↑, pulmonary function↓)
High alkalinity (skin and respiratory irritation↑)	Dissolved metal content (skin irritation↑)	System stagnation/rancidity (respiratory illness↑)
Unstable emulsions (skin irritation↑)	Organic acid production (skin irritation↑)	Presence of human pathogens (rare, poor survival rates, infrequent effects on health)

Industrial lubricants have undergone numerous changes and modifications in formulations over many decades in response to knowledge gained about the potential health effects of various constituents through intensive research and testing. These improved products must meet or exceed stringent end-user technical specifications for machining performance. Concurrent with R&D activities of MWF manufacturers and suppliers, modern-day MWF formulations must comply with both internal and federal regulatory health and safety requirements that are optimally protective for workers.

Data on the potential health effects of chemicals contained in MWF formulations are generated from two primary sources: (1) toxicology studies of animals where health effects are extrapolated to humans and (2) epidemiology studies of exposed human populations. Toxicology studies are typically conducted using a single chemical or a defined mixture *vis-à-vis* controlled exposure populations. Epidemiology studies eliminate the need for species-to-species extrapolation but introduce other variables. Unlike controlled conditions employed in animal experimentation, real-world exposures to chemicals may occur by way of multiple routes and may be of inconsistent durations and frequencies that fluctuate over time. Many epidemiologic studies have been conducted on populations working with MWFs, and these data can provide a comprehensive picture of the potential health hazards of exposure to MWFs and serve as a guide for the control of these exposures.

MWF testing occurs on several levels. Some manufacturers of MWFs conduct toxicological testing of their products as a whole to ascertain the health effects of the tested formulations, but the utility of these tests is limited because of changes in composition that happen during use. Most MWF manufacturers routinely submit samples of their neat (unused) formulations for quality control testing to ensure the product meets internal standards prior to distribution to machining customers. Finally, data obtained from representative grab samples of in-use (production line) MWFs help determine changes in the composition of the fluid at a given moment in time. Changes in selected parameters determine the overall condition of the matrix of fluid samples and influence decisions about the need for fluid maintenance supplementation. It is also beneficial to monitor these accumulated production line data over time to establish trends and identify the time frame in which certain events occurred.

17.4 HEALTH EFFECTS ASSOCIATED WITH MWF EXPOSURES

17.4.1 DERMATOLOGICAL CONDITIONS

OSHA reports that, in the United States, the rate of skin disease exceeds recordable respiratory illnesses.⁷ Dermatitis is the most commonly reported medical problem reported by workers who utilize MWFs. In 2010, 34,400 recordable skin diseases were reported by the Bureau of Labor Statistics (BLS) at a rate of 3.4 injuries per 10,000 employees, compared with 19,300 respiratory illnesses with a rate of 1.9 illnesses per 10,000 employees.⁸ Both contact and allergic dermatitis can occur as a result of skin contact with in-use MWFs. Specifically, contact dermatitis (irritant contact dermatitis, allergic contact dermatitis) is associated with water-based MWF exposures. Skin diseases such as folliculitis, oil acne, and keratoses may occur when the skin of susceptible individuals is exposed to some minimally refined straight oils over time. There are significant factors in the causation of MWF-related skin disorders:

- Fluid concentration
- pH
- Duration of exposure
- Extent of contamination
- Skin type
- Age
- History of previous exposures
- Presence of other skin disease
- Integrity of dermal layer

Most often, more than one causative factor is responsible for cases of contact dermatitis. Also, additives such as amines, petroleum sulfonate, and some biocides have been associated with the diagnosis of contact dermatitis. Skin sensitization, which is an allergic response to a chemical or a component in a fluid, has also been reported. Some biocides and corrosion inhibitors, including isothiazalones, formaldehyde, and mercaptobenzothiazoles, have been reported to have sensitization potential. Metal allergy dermatitis may also occur due to the dissolution of small amounts of metallic ions from some alloys being machined. Nickel and chromium, found in stainless steels, and cobalt, used as a binder in tungsten carbide tooling, are three of the most common metal skin sensitizers.

Many components in MWFs have been tested in animals for acute, oral, and dermal lethality (LD_{50}), as well as for skin and eye irritation. For example, severely processed mineral oils are classified as relatively nontoxic, the LD_{50} being greater than 10 g/kg on oral exposure in rats and greater than 3 g/kg following dermal application in rabbits. Severely processed mineral oils are also classified as mild to moderate skin and eye irritants. Most other components in MWFs are classified as moderately toxic to nontoxic when evaluated in short-term, acute, LD_{50} studies.

The prevention of dermatitis in its various manifestations is readily achievable:

- Use of suitable PPE (e.g., gloves, arm guards, face guards, aprons, etc.)
- Prudent housekeeping (e.g., cleaning contaminated tools, promptly removing oil-soiled clothing, cleaning up fluid-drenched workbenches)
- Management support of skin care programs
 - Promoting personal hygiene (washing hands)
 - Cleanliness of workstations
 - Worker training on dermal hazards
 - Regular use of skin barrier creams

17.4.2 RESPIRATORY CONDITIONS

The inhalation of MWF aerosols is a common route of occupational exposure. Workplace aerosols—mists—in an industrial metalworking environment are produced as machining fluids continuously flood cutting and grinding tools and workpieces (machined materials). MWF mist consists of suspended liquid droplets formed by breaking up liquids into a dispersed state, such as by splashing or foaming, or by condensation from the gaseous state. In the metalworking environment, it is generally recognized that there are three mechanisms of mist formation that may operate simultaneously.

- Evaporation at elevated temperatures and condensation
- Mechanical motion
- Bubbling of the MWF

The component distribution in the shop air is dependent on which mist formation mechanisms come into play during the machining or grinding process, as heat is generated. When fluid enters the hot cutting zone, volatile components vaporize and then recondense to form small (less than 1 μm) particles. The chemical composition of recondensed vapors is a reflection of the more volatile components of the formulation. Compositionally, these droplets will be the same as the bulk fluid, and larger particles will not migrate far from the point of generation.

Aeration of the MWF, such as when a fluid foams or is excessively agitated, creates other mist particles. In this case, when the fluid comes to rest, entrained air can escape, causing mist to form as bubbles break. White and Lucke have shown that some components, such as volatile short-chain organic acids, can selectively concentrate in this fraction.⁹ Turchin and Byers have shown that tramp oil, a frequent contaminant of an in-use MWF, increases the amount of mist.¹⁰

Aside from mist created in the machining or grinding operation itself, mist can be generated in the shop from metalworking fluids circulating in open troughs in central system returns, from compressed air blow-off of parts before inspection or packaging, or from parts washers. Compositions of products used for parts washing may be similar to MWFs used in the shop, or they may be more closely related to more traditional alkaline cleaners and comprised of nonionic and anionic surfactants and alkaline detergent builders, such as sodium or potassium polyphosphates and carbonates or sodium or potassium hydroxide.

Finally, MWFs are usually not the only products in the shop atmosphere. Depending on the facility, the shop atmosphere may also contain welding fumes, tow motor exhaust, and other metallic and nonmetallic particles.

Beginning in the 1980s and extending to recent times, a large body of peer-reviewed published research has accumulated about acute respiratory effects resulting from exposure to MWFs in both laboratory animals and in human cohorts.¹¹ Summarily, decreases in respiratory (lung) function (generally measured by the spirometry parameter forced expiratory volume [FEV₁]) consistently have been identified in subjects who inhale MWF mists as opposed to nonexposed populations. It is generally accepted that a poorly maintained fluid (i.e., dirty fluids) or alkaline pH may play a role in promoting adverse respiratory effects, although there may be exceptions, depending on the type of MWF used, the extent of ventilation patterns in a given facility, and the subjects selected for study. A variety of nonmalignant respiratory illnesses may result from occupational exposures to MWFs, such as acute airways irritation, chronic bronchitis, asthma, and hypersensitivity pneumonitis (HP).

HP (or extrinsic allergic alveolitis) is an immunologically mediated inflammatory lung disease that occurs in susceptible individuals as a result of repeated exposures to inciting substances (antigens) such as organic dusts, animal proteins, microorganisms, and low molecular weight chemicals. Early medical intervention with good prognosis includes moving patients away from problematic environments. Affected individuals who continue to be exposed to problematic aerosols may experience gradual decrements in pulmonary function. It has been determined that HP occurs as a result of antigen–antibody mechanisms that lead to an accumulation of polymorphonuclear leukocytes (PMNs) in alveoli and airways, and the subsequent influx of mononuclear cells into these sites results in non-necrotizing granulomas. The chronic stage of HP is characterized by irreversible pulmonary fibrosis—that is, the occlusion of respirable areas of lung tissue and thus decreased pulmonary function. Hypersensitivity pneumonitis is a well-documented pulmonary disease and, depending on its origin of exposure, HP is known by various names, two of which are *bird breeder's lung* and *farmer's lung*. The subject of MWF-related HP came into prominence in the 1990s when researchers identified clusters of HP among workers exposed to MWF aerosols.¹² Later on, in 2002, *Mycobacterium immunogenum* (MI) was theorized as being a possible causal agent of HP among workers who inhaled MI-laden aerosols. However, this putative correlation was not always consistent, since HP was also diagnosed among machinists who worked with fluids devoid of MI content. Although it is postulated that some HP cases may be related to certain bacterial contaminants in MWFs, it is not clear whether a reduction of bacterial densities in active fluids by selective biocide treatments and/or decreasing worker aerosol exposures will prevent or curtail the development of HP. Also, biofilms—attached communities of bacteria and fungi—which are found throughout surfaces of MWF distribution systems and are resistant to biocides, appear to have HP involvement. Some research suggests that biofilms support fast-growing mycobacteria, which may be linked to cases of HP.¹³ New and relatively fast and inexpensive techniques to assess species diversity within MWF microbiomes and their population sizes are in development as a means to control microbial proliferation in MWFs.

Asthma is an airways disease with a marked variability in airflow limitation, and it can be induced by exposure to an immune sensitizer or an irritant. Whether initially induced by a sensitizer or irritant, symptomatic episodes of immunologic or irritant asthma can be triggered by subsequent exposure to the specific causative agent or any irritant, even at concentrations substantially lower

than those tolerated by nonasthmatic persons. NIOSH noted in its MWF criteria document that there was increasing evidence to suggest that a worker's occupational asthma is more likely to become chronic (with irreversible airflow limitation and continuing airway hyperresponsiveness even after removal from exposure) the longer the worker continues to be exposed after the onset of asthma. Results from a number of studies indicate that there is an elevated risk of asthma among workers exposed to MWF aerosol concentrations found in large automotive shops. It is stated that "MWF-induced asthma appears to involve known sensitizers in some cases but various other agents (possibly acting through irritant or inflammatory mechanisms)¹⁴ may cause a high proportion of cases." Listed sensitizers are ethanalamine and other amines, colophony, pine oil, tall oil, metals and metallic salts, castor oil formaldehyde, chlorine, various acids, and microbial contaminants including Gram-negative bacterial endotoxin.

Endotoxin is the term applied to the lipopolysaccharide (LPS) portion of the outer membrane of Gram-negative bacteria (GNB), although there is variability in the chemical composition of LPS in different GNB species. Endotoxin is a well-known pyrogenic (fever-inducing) agent in mammals and was the basis for the old rabbit pyrogen test. That test required the injection of a small amount of the test material into a rabbit's blood stream and monitoring for temperature increases. The *Limulus* ameobocyte lysate (LAL) test has been used since the 1970s to detect the level of endotoxin contamination of pharmaceuticals and medical devices, replacing the old rabbit test. An ELISA recombinant protein, factor C, is now frequently used for endotoxin testing.

Endotoxin can induce strong immunologic responses and thus has significance for inhalation exposure from MWF aerosols.¹⁵ Once neat MWF concentrates are mixed with water and introduced into machining operations as industrial lubricants, they are immediately populated by many types of environmental microorganisms, including many GNB species that survive and proliferate readily in the harsh chemical environments found in agitating and recirculating fluids in central systems and individual sumps. Endotoxin from these GNB will exist in active MWFs in the form of intact cells, cell fragments, and GNB-exuded LPS. Consequently, through the processes of mist formation (described earlier) endotoxin will be transported to the breathing zone of exposed workers. Various investigations of respiratory health effects among workers exposed to endotoxin in MWF industries show similar results to those of workers employed in textile and fiberglass industries. Specifically, MWF industries showed that endotoxin can potentially have adverse respiratory effects (decreased pulmonary function), depending on individual tolerance and the frequency and amount of exposure. Some studies have demonstrated that exposure to used MWFs contaminated with endotoxin and other microbiological contaminants produced acute adverse respiratory effects in laboratory animals to a greater degree than exposure to neat MWF aerosols.

17.4.3 CARCINOGENICITY OF MWF MATERIALS

Numerous epidemiology studies have evaluated the carcinogenic potential of occupational exposure to oil mists and MWFs. The majority of cancer types reported have been skin (scrotal), respiratory, or gastrointestinal. Cases of scrotal cancer have been extensively reported in the literature, primarily associated with the use of poorly refined oil in conjunction with poor personal hygiene.¹⁶ Historically, one of the initial concerns in this area arose with the report that diethanolnitrosamine, which has been shown to be a liver carcinogen in laboratory animals, could form in MWFs that contained both nitrites and diethanolamine (DEA). Also, there has been concern over the potential carcinogenicity of some petroleum-based mineral oils. The nitrosamine problem was addressed relatively easily in the industry by simply avoiding the combination of secondary amines and nitrites. The concern with oil is more complex and involves a critical component of all but synthetic MWFs.

Possible causal relationships between exposure to oil mist and cancer of the respiratory or gastrointestinal tract is difficult to establish as tumors in these organs are common, and many other factors, such as smoking and diet, could be responsible. Additionally, few of these studies provide

analytical data on either the bulk fluid, including the critical question of the refining history of the oil, or the air contaminant levels associated with the effects reported, making extrapolation of the results to other settings difficult.

There are limited data on the carcinogenicity of individual components used in MWFs. However, many fluid manufacturers follow health and safety research developments involving their products closely and may opt to remove constituents that appear to present problematic profiles. For example, DEA was under intensive animal research that yielded tentative data to prompt many formulators to remove DEA and its alkanolamides from their MWF formulations during the 1990s. Continuing research on MWF products and constituents is constantly providing new data with which manufacturers can hopefully make better decisions to provide safer products.

The issue with mineral oils has largely been addressed by the widespread usage of highly refined (i.e., severely hydrotreated) oils to remove potentially problematic constituents. In the past, the term *mineral oil* has been used to describe oils derived from coal, shale, petroleum crude oil, and even animal and vegetable sources. There has been little recognition of the vast differences in the production and uses of mineral oils and their chemical, physical, and toxicological characteristics.

Particularly since 1985, the trend has been toward more highly refined oils, with the removal of polyaromatic hydrocarbons (PAHs), constituents believed to be major factors in imparting carcinogenic activity to oil products. Consequently, animal studies have been conducted on refined mineral oils derived from these new processing techniques in order to evaluate carcinogenic potential—primarily mouse skin–painting studies. These studies are fairly common in toxicology and considered to be relatively accurate in predicting skin carcinogenic potential in humans. Data from these animal carcinogenicity studies are the primary basis for the following conclusions drawn by the International Agency for Research on Cancer (IARC):¹⁷

- There is sufficient evidence of carcinogenicity for
 - Untreated vacuum distillates
 - Acid-treated oils (which includes caustic neutralization, dewaxing, or clay treating)
 - Aromatic oils
 - Mildly solvent-refined oils
 - Mildly hydrotreated oils
- There is no evidence of carcinogenicity for
 - Severely solvent-refined oils
 - White oils (when administered by routes other than intraperitoneal injection)
- There is inadequate evidence to evaluate severely hydrotreated oils or oils that have been mildly solvent refined with subsequent mild hydrotreatment.

17.5 HISTORICAL NOTES OF MWF STAKEHOLDER ACTIVITIES TO PROMOTE HEALTH AND SAFETY

The health and safety aspects of MWFs involve a variety of stakeholders, including the following:

- Machinists and other production workers
- Researchers
- Health-care providers
- Industrial hygiene and safety specialists
- Product R&D researchers (company, academic, federal)
- MWF suppliers (raw materials, additives)
- Manufacturer management and health and safety oversight personnel
- Employee representatives
- Regulatory agencies (local, state, federal)

- Legislative bodies
- International cohorts/partners
- MWF distributors
- Trade associations
- Consensus standards organizations
- Industry interest groups

17.5.1 OSHA MWF STANDARDS ADVISORY COMMITTEE

In December 1993, the International Union, United Automobile, Aerospace, and Agricultural Implement Workers of America (UAW) petitioned OSHA to take emergency regulatory action to protect workers from the risks of occupational cancers and respiratory illnesses due to exposure to MWFs. OSHA sent an interim response to the UAW, stating that the decision to proceed with rulemaking would depend on the results of the OSHA Priority Planning Process, which eventually issued a report that identified MWFs as an issue worthy of agency action. Subsequently, in 1997 the OSHA Standards Advisory Committee (SAC) was impaneled to make recommendations to OSHA's assistant secretary of labor regarding MWFs. The membership of the committee was balanced and included representatives from industry, labor, federal and state safety and health organizations, professional organizations, and national standards-setting groups. A final report was accepted and issued in 1999 with the following OSHA recommendations:¹⁸

- Action to mitigate adverse health effects associated with exposure to MWFs
- Recognition that evidence for health conditions, including cancer, is evolving
- Use of a defined occupational exposure limit
- Use of systems management to control exposures
- Focus on cutting, machining, grinding, and honing operations
- Permissible exposure limit (PEL) of 0.5 mg/m³ (total particulate), 8 h, TWA

Although a majority of the SAC recommended that OSHA promulgate a comprehensive standard to protect employees from the adverse effects of MWFs and the material impairment of health, this recommendation was not accepted by the assistant secretary. (The dissenting minority had recommended nonregulatory alternatives.) Instead, OSHA published the "Metalworking Fluids Best Practices Manual" in 2001, with the disclaimer that it was only advisory and informational in nature, it was not a new standard or regulation, and it created no new legal obligations. A relatively recent paper addresses the issues of the SAC.¹⁹

Since occupational exposure limits (OELs) do not protect workers against microbial contaminants that cause asthma or HP, an integrated approach to worker protection has been suggested—that is, a combination of OELs, the identification of hazards, and MWF management control and engineering, administrative, and PPE.²⁰ These include but are not limited to

- Proper selection of MWFs and their additives
- Maintenance of fluids to minimize the growth of microbial contaminants
- Minimizing and controlling the unnecessary contamination of fluids with other substances, such as tramp oil
- Machine enclosures and mist collectors to minimize the generation of MWF aerosols in the workplace environment
- The use of cycle times and other administrative controls to avoid the unnecessary generation of aerosols in the workplace

17.5.2 ORGANIZATION RESOURCES COUNSELORS

In 1999, a committee working under the auspices of Organization Resources Counselors (ORC), a human relations consulting firm specializing in OSHA affairs, published an Internet-based guide

called “Management of the Metal Removal Fluid Environment.”²¹ Written by industry experts, the guide included information on MWFs, facilities and equipment, ventilation and controls, metal removal fluid systems, and MWF systems management program. Topics included

- How to manage fluids (testing, maintenance)
- Environmental issues
- Health issues
- Information for employers and employees

The guide was unanimously recommended by the OSHA MWF SAC committee.

17.5.3 MWF SYMPOSIUMS

From 1995 to 2015, a series of five MRF/MWF symposiums were organized by diverse groups of stakeholders with representatives from trade associations, industry groups, worker representatives, regulators, academics, and researchers.

- 1st (1995) “The Industrial Metalworking Environment” (Dearborn, Michigan)
- 2nd (1997) “The Industrial Metalworking Environment” (Detroit, Michigan)
- 3rd (2008) “Assessment and Control of Metal Removal Fluids” (Dearborn, Michigan)
- 4th (2011) “Innovation | Regulation | Application” (Barcelona, Spain)
- 5th (2015) “Moving Forward through Cooperation and Innovation” (Rosemont, Illinois)

The focus of topics at symposiums has primarily been on worker health, fostering better understanding, and the control of MWF exposures. In general, numerous presentations have been given by various experts on a wide range of scientific and engineering subjects relevant to the health and safety of workers in MWF facilities. A major paradigm shift occurred when symposium organizers acknowledged in 2008 that the MWF industry is global in nature and various countries share similar health and safety concerns. Therefore, in 2011, the fourth MRF symposium was held in Barcelona, Spain, rather than the Detroit area of Michigan.

Numerous organizations have been instrumental in organizing, sponsoring, or cooperating in one or more of the aforementioned symposiums, including the following:

- American Automobile Manufacturers Association (AAMA)
- American Association for Aerosol Research (AAAR)
- The American Federation of Labor and Congress of Industrial Organizations (AFL-CIO)
- American Industrial Hygiene Association (AIHA)
- American Petroleum Institute (API)
- American Society of Safety Engineers (ASSE)
- Association of International Automobile Manufacturers (AIAM)
- Association for Manufacturing Technology (AMT)
- Automotive Industry Action Group (AIAG)
- Chemical Industry Institute of Toxicology (CIIT)
- Chemical Manufacturers Association (CMA) Alkanolamines Panel
- Environmental Protection Agency (EPA)
- Independent Lubricant Manufacturers Association (ILMA)
- International Association of Machinists and Aerospace Workers (IAMAW)
- Independent Union of the European Lubricant Industry (UEIL)
- International Union, United Automobile, Aerospace, and Agricultural Implement Workers of America (UAW)
- National Institute for Occupational Safety and Health (NIOSH)

- Occupational Safety and Health Administration (OSHA)
- Ontario Ministry of Labour (OMI)
- Society of Manufacturing Engineers (SME)
- Society of Tribologists and Lubrication Engineers (STLE)

The symposiums have been important in providing forums for a wide spectrum of MWF/MRF stakeholders to exchange ideas and present state-of-the-art research results on health and safety in machining industries.

17.6 CONCLUSION

The twenty-first century presents many technological challenges for MWF manufacturers, suppliers, and end users involved with machining industries. There will be a need for more innovative techniques and exacting technical specifications to meet the demands for increasing machine speeds, precision machining, and feedstock rates. Concurrently, there are many health and safety aspects in the use of metalworking fluids that will influence how associated industries will evolve into the future. Some of these aspects include lowering the toxicity of formulated products and reducing the health impacts of inevitable contaminants, especially ubiquitous environmental microorganisms and their biomolecules (e.g., endotoxins). Acute respiratory and some chronic effects of MWF exposures can occur as a result of microbial growth in water-miscible MWFs. Therefore, adherence to reducing exposures to 0.5 g/m³ or less and attention to fundamental industrial hygiene practices will help to minimize potential health effects.

Primary consideration must be given to reducing exposures through engineering controls, the management of MWF systems, and industrial hygiene, as follows:

- Optimize machine tool feeds and speeds, since excessively high feeds and speeds increase the amount of aerosol generated.
- Minimize coolant flow rates, consistent with desired part finish and dimensions, and with movement of generated chips or swarf.
- Use flooding instead of spray application, wherever possible.
- Control tramp oil contamination, since excessive oil content increases mist.
- Maintain good microbiological control of fluids.
- Install and maintain local and general exhaust ventilation to reduce inhalation exposures.

REFERENCES

1. OSHA, Safety and health topics: Metalworking fluids. Available at: <https://www.osha.gov/SLTC/metalworkingfluids> (Accessed June 2, 2017).
2. OSHA, Metalworking fluids: Safety and health best practices, 2001. Available at: https://www.osha.gov/SLTC/metalworkingfluids/metalworkingfluids_manual.html (Accessed June 2, 2017).
3. NIOSH, U.S. Department of Health and Human Services, DHHS Publication 98–102, Cincinnati, OH, 1998. Available at: <https://www.cdc.gov/niosh/doc/98-102/default.html> (Accessed June 2, 2017).
4. Gordon, T., Metalworking fluid: The toxicity of a mixture, *Toxicol. Environ. Health A.*, 67(3), 209–219, 2004.
5. Piacitelli, G., Sieber, W., O'Brien, D., Hughes, R., Glaser, R., and Catalano, J., Metalworking fluid exposures in small machine shops, *Am. Ind. Hyg. Assoc. J.*, 62, 356–370, 2001.
6. Ross, A., Teschke, K., Brauer, M., and Kennedy, S., Determinants of exposure to metalworking fluid aerosol in small machine shops, *Ann. Occup. Hyg.*, 48, 383–391, 2004.
7. OSHA, Safety and health topics: Dermal exposure. Available at: <https://www.osha.gov/SLTC/dermalexposure/> (Accessed June 2, 2017).
8. Bureau of Labor Statistics, U.S. Department of Labor, Employer-reported workplace injuries and illnesses: 2014, USDL-15-2086. Available at: www.bls.gov/iif/oshsum.htm (Accessed June 2, 2017).

9. White, E., and Lucke, W., Effects of fluid composition on mist composition, *Appl. Occup. Environ. Hyg.*, 18, 838–841, 2003.
10. Turchin, H., and Byers, J., Effect of oil contamination on metalworking fluid mist, *Lubr. Eng.*, 56(7), 21–25, 2000.
11. Howell, J.K., Lucke, W.E., and White, E.M., Health and safety aspects in the use of metalworking fluids, in *Metalworking Fluids*, 2nd ed., Byers, J.P., ed., CRC Press, Boca Raton, FL, 337–376, 2006.
12. Kriess, K., and Cox-Ganser, J., Metalworking fluid: Associated hypersensitivity pneumonitis: A workshop summary, *Am. J. Ind. Med.*, 32, 423–432, 1997.
13. Trany, E.A., Microorganisms in metalworking fluids: Current issues in research and management, *Internal. J. Occup. Med. Environ. Health*, 26(1), 4–15, 2013.
14. Suuron, K., Henriks-Eckerman, M-L., Riala, R., and Tuomi, T., Respiratory exposure to components of water-miscible metalworking fluids. *Ann Occup Hyg*, 52(7):607–614, 2008.
15. Milton, D., Biological responses to endotoxin in the airways and alveoli, *Metalworking Fluids Symposium II: The Industrial Metalworking Environment; Assessment and Control of Metalworking Fluids*, Detroit, MI, September, 1997, Symposium proceedings, American Automobile Manufacturers Association, 59–65, 1998.
16. Bingham, E., Trosset, R., and Warshawsky, D., Carcinogenic potential of petroleum hydrocarbons: A critical review of the literature, *J. Environ. Pathol. Toxicol.*, 3, 483–563, 1979.
17. *IARC Monographs on the Evaluation of Carcinogenic Risk of Chemicals to Humans*, Vol. 33, International Agency for Research on Cancer, WHO, Lyon, France, 1984.
18. Final report of the OSHA Metalworking Fluids Standards Advisory Committee, OSHA, Washington, DC, 1999. Available at: http://www.osha.gov/SLTC/metalworkingfluids/mwf_finalreport.html.
19. Mirer, F., New evidence on the health hazards and control of metalworking fluids since completion of the OSHA Advisory Committee report, *Am. J. Ind. Med.*, 53(8), 792–801, 2010.
20. Cohen, H., and White, E., Metalworking fluid mist occupational exposure limits: A discussion of alternative methods, *J. Occup. Environ. Hyg.*, 3(9), 501–507, 2006.
21. Management of the metal removal fluid environment, ORC Worldwide, Washington DC, 1999. Available at: <https://www.quakerchem.com/our-responsibility/product-impact/metalworking-resources/orc/> (Accessed June 2, 2017).