Review

Environmental and Health Aspects of Metalworking Fluid Use

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Abstract

The utilization of metalworking fluids in the metal machining technological process provides, apart from benefits, certain negatives that are mainly associated with air contamination of the working environment. Typical health problems that result from inhalant exposure of metalworking machine operators to the metalworking fluid mist include respiratory diseases (asthma, chronic bronchitis, hypersensitivity pneumonitis), cancer, and skin diseases. Possible health risks posed by the utilization of metalworking fluids, various methods for measuring their concentration in the working environment, and treatment of MWFs are discussed. A typical particle size range of liquid aerosol (oil mist) is in the range from 0.1 to 10 µm and more than 75% of MWF particulate matter is located in the sphere of respirable fraction (particle size less than 5 µm) that poses the highest risk for the human body. MWF aerosol mass concentration in the working atmosphere varies depending on the type of working activity, and MWFs used in a wider range (average exposure in the range of 0.55 to 5.36 $mg\cdot m^{-3}$). Attention also should be paid to microbiological contamination of water-based MWFs, when they are used or stored after dilution for longer term. The most often occurring microbial species at considerable concentration is the bacteria *Pseudomonas pseudoalcaligenes*. Other important species include *Mycobacterium*, *Pseudomonas*, *Morganella*, *Citrobacter freundii*, *Acinetobacter, Bacillus*, *Fusarium*, *Trichoderma*, *Penicillium*, etc.

Keywords: metalworking fluids, MWF determination, inhalation exposure, working area, metal processing, mist, biological aerosol

Introduction

Metalworking fluids are particularly used in metalworking machinery operations (grinding, cutting, planing, drilling, turning, milling, etc.), primarily for the purpose of heat removal from the treatment, purification, and lubrication to reduce friction of metal parts, thereby simultaneously increasing their lifetime [1]. In English the term "metalworking fluids" (MWFs) is used and this shortcut will be used in this paper (synonyms: machining fluids, cutting fluids, processing fluids, lubricants, oil mist, coolants, etc.). Apart from the advantages, the use of MWFs in metalworking processes also brings certain drawbacks due to the production of polydisperse aerosols,

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which contaminate the working atmosphere and give rise to serious health damage.

Typical health problems of metalworking machine operators resulting from inhalation exposure to liquid aerosol from the process fluids include respiratory diseases (asthma, chronic bronchitis, hypersensitivity pneumonitis), cancer, allergies, and skin diseases. This paper deals with the clarification of the mist creation mechanisms during the technological process and with the description of potential health risks from exposure to MWFs. In the methods review of liquid aerosols concentration measuring in the working environment, the methods for quantitative assessment of health risks and procedures to reduce the risk of excessive exposure to MWFs are presented.

MWFs are used in large quantities worldwide (in the year 2010, the consumption in Europe, including Russia, amounted to 610,000 t) [2] and they pose a risk to the staff, but also to the environment during their subsequent disposal or processing as waste. For these reasons the increased attention is paid to the cutting fluids and several review articles dealt with this issue [3-7, 57]. Currently, entering the key words "metalworking fluids" brings up more than 500,000 references that can be found in patent literature [8].

Properties and Composition of MWFs

The metal cutting process is a complicated physical change in which sliver is separated from a base material and only part of the energy delivered by a machine tool is spent in the process. The rest of the energy is transformed into heat, which is undesirable and causes rapid tool wear, heat influence of the workpiece, changes in the structure, etc. This heat must be constantly distracted from the place of processing. Heat dissipation is provided by the surrounding environment, which can be air, gas, mist or processing fluid, which is led to the place of treatment [9].

Processing fluids are complex mixtures. Their task is cooling, lubrication, and removal of metal chips from tools and metal parts created during processing. According to thermophysical properties, the method of use and oil content makes it possible to distinguish four basic categories of MWFs: pure oils, soluble oils, semi-synthetic, and synthetic fluids.

Pure oils are not water-soluble and are primarily used for operations that require lubrication. Most pure oils are highly refined products made from crude oil and animal fats or vegetable oils. The most popular is a group of mineral oils and oil-based oils and it is often refined by solvents to reduce levels of polycyclic aromatic hydrocarbons. They may also contain a variety of components, including chlorinated paraffins, compounds containing sulphur, trikresylphosphates, etc. [10]. They are used without dilution and have the best lubricating properties, as well as good corrosion protection and resistance to biodegradation, but their cooling abilities are the weakest in comparison with other types of MWFs [11].

Soluble oils consist of petroleum or mineral oil in combination with emulsifying agents and additives. They are acting in the form of emulsions or emulsifiable oils. Similarly to pure oils, they provide good lubrication (reduction of friction) and good cooling, but not as strong as in the case of semi-synthetic or synthetic fluids.

Semi-synthetic liquids are a hybrid between soluble oils and synthetic fluids that combines the advantages of both groups (satisfying performance and lubrication properties, good biodegradation resistance, and strong cooling capacity) [12].

Synthetic fluids contain no mineral oils. They are a mixture of organic substances and additives and content of water is 70-95% (vol.). They are very clean and provide good lubrication, corrosion protection and the best conduction of heat. After mixing, they are transparent, so they provide good visibility in metalworking processes.

Composition of the four MWF classes is demonstrated in Table 1 [50].

However, in a broader sense there are basically only two types of MWFs: oil-based (pure oils and soluble oils) and soluble in water (emulsifying oils, synthetic or semi-synthetic liquids). Oil-based MWFs are stable fluids, which are the right choice for some machining applications. In comparison to the past, water-soluble MWFs are becoming increasingly popular. However, they provide an excellent environment for the growth of microorganisms and they may contain alkanolamines [13], boron compounds, emulsifiers, ionic and non-ionic surfactants, corrosion inhibitors, detergents, odorants, anti-foaming and anti-mist agents, abrasives, and biocides that limit microorganism growth [14]. Each of these components of MWFs may contribute to the deterioration of impacts on the natural and working environments, but also of the health effects. The nature and severity of these effects depend on the particular composition of MWFs [15, 16], as well as on the specific conditions during the metalworking operations.

The Mechanism of Mist Creation in Metalworking Processes

Primary mechanisms, through which the processing fluids are converted to liquid aerosols in the environment, are:

a) Evaporation due to high cutting temperature
b) Dispersing due to the rotation of tools and workpieces
c) Spatter induced by the impact of fluid under pressure to the tool, workpiece, or machine (atomization) [17-20].

Atmadi et al. [21] developed a mathematical model that can be used to predict the distribution curve of liquid aerosol, resulting as a splash of MWFs. In this model, size distribution of the aerosol droplets is expressed as a statistical variable in the distribution function and its amount depends on several parameters of the processing fluid (density, surface tension, flow rate at the nozzle exit, average of current expressed as a dimensionless Weber number).

The mechanism of so-called rotational atomization (the process of disintegration of a liquid stream into fine droplets affected by centrifugal force) is addressed by several authors [22, 23]. A typical particle size range of liquid aerosol (oil mist) is in the range from 0.1 to 10 μm. The fractional analysis has shown [24] that, by the mass concentration 5-10% of particles are less than 0.5 μm, 10-20%

Table 1. Typical composition of the four MWF classes (modified according to [50]).

Component	Function	Amount (undiluted)			
		Pure oil	Soluble oils	Semisynthetics	Synthetics
Water	Solvent, coolant, diluent	Dissolved 10-500 ppm	5-40 parts/ 1 part concentrate	10-40 parts/ 1 part concentrate	10-40 parts/ 1 part concentrate
Mineral oil	Lubricant	60-100%	30-85%	5-30%	*
Emulsifiers	Emulsifies	*	5-20%	5-10%	5-10%
Chelating agents	Tie up ions in solution	*	0-1%	0-1%	0-1%
Coupling agents	Stabilize	*	1-3%	1-3%	1-3%
Antiweld agents	Prevents welding	0-20%	0-20%	0-10%	0-10%
Surfactant wetting agents	Reduces surface tension	0-10%	5-20%	10-20%	10-20%
Anti-foaming agents	Prevents foaming	0-500 ppm	0-500 ppm	0-500 ppm	0-500 ppm
Anti-mist agents	Reduces misting	**	**	*	*
Alkaline reserve	Acts as buffer control	*	2-5%	2-5%	2-5%
Corrosion inhibitors	Prevents rust film barier	0-10%	3-10%	10-20%	10-20%
Dyes	Identify leak detection	*	0-500 ppm	0-500 ppm	0-500 ppm
Biocides	Control micro-bial contaminant	*	0-2%	0-2%	0-2%
Extreme pressure additives	Acts as reaction lubricant films	0-40%	0-20%	0-120%	0-10%
Detergent	Prevents deposit formation	**	**	**	**
Odorant	Masks odor	**	**	**	**
Plasticizers	Reduces tackiness	**	**	*	*

*not present in this MWF class, **usually present in this MWF class

of particles are less than 1 μm, 50-70% of particles are less than 2 μm, 75-95% of particles are less than 5 μm, and 100% of particles are less than 10 μm. It follows that more than 75% of MWF particulate matter is located in the sphere of the respirable fraction that poses the highest risk for the human body.

Health Effects of MWFs

Processing fluids used in metalworking processes carry a high risk of environmental pollution and have a negative impact on humans [25]. In human risk assessment of metalworking machine operation using MWFs, the most important issue is quantification of their amount in the air (determination of mass concentration) due to evaporation of liquid aerosol trapped by the filter during sampling.

Exposure of operating staff to MWFs, occurs by inhalation of aerosols or by skin contact – touching contaminated surfaces, using parts and equipment, fluids splashing, and aerosol deposition on the skin. Inhalation of MWF aerosols can cause irritation of the throat (pain, burning throat), nose (rhinorrhea, congestion, and nosebleeds) and lungs (cough, shortness of breath, increased mucus production). MWF aerosol exposure is often associated with chronic inflammation of the bronchi (bronchitis), hypersensitive pneumonitis, and deterioration of existing breathing problems (asthma) [26-28]. Skin contact with processing fluids can cause allergic or irritant contact dermatitis, whose manifestation depends on the chemical composition of the MWFs, presence of ingredients, type of contaminants contained in MWFs, processed metal composition (e.g. toxicity and allergic reactions to Ni, Cr, Cd, etc.), and individual predisposition to allergies [29]. Petroleum products can also cause the formation of acne [30, 31].

Splinter machining of metals, in which various emulsions and cutting oils for cooling are used, is the most risk production process in relation to skin diseases. These fluids are characterized by significant irritant effects on the skin, which are also amplified by other specific working conditions (humid working environment and its alternation with dry working cycles, possible minor mechanical injury - abrasion of the skin, aging of coolants and their heavy metal pollution, inappropriate use of cleaners and inadequate ways to clean dirty skin, using wrong chemicals for cleaning machines, etc.). A significant role in the development of these diseases has a low level of sanitation, failure of hygienic standards and underestimation of the risk by workers. Information about the adverse health effects associated with occupational exposure to MWF aerosols can be found in the document NIOSH [50].

In recent years a number of studies have found a causal relationship between working with MWFs and various cancer types (including leukaemia, laryngeal cancer, esophagus cancer, pancreatic cancer, stomach cancer, cancer of the rectum, bladder cancer, cancer of the scrotum, and skin cancer) of exposed workers [32, 33]. Mirer [25] carried out an analysis of health damage during work with MWFs where, from 227 reported results, 26 were related to cancer, 58 to respiratory effects, 32 to dermal effects, 45 to microbial contamination, and 76 to exposure measurement. A systematic review of respiratory outbreaks associated with exposure to water-based MWFs is given in [3, 5].

Requirements for MWFs

Basic requirements for MWFs include the following attributes:

a) They must have good cooling and lubricating ability, which are conditioned by high value of specific heat, high value of vaporization heat, high wetability, adhesion and penetration ability, ability to generate quickly suitable chemical compounds with workpiece metals and tools, and low foaming ability
b) They must not cause corrosion
c) They must not violate machine coatings
d) They must be wholesome (low toxicity and biological irritation) [34]

Universal metalworking fluid does not exist, therefore there are more types commonly used, which are selected according to the type of machining operations and working conditions. Their effect is greatly influenced by the amount of MWFs, the pressure, and the mode of fluid flow to the destination.

Security of MWFs is characterized by the following criteria:

a) Toxicity
b) Inhalation irritation
c) Carcinogenicity
d) Ocular irritation
e) Dermatological irritation
f) Flammability

There are quantifying units: median lethal dose LD_{50}, median lethal concentration LC_{50}, and flashpoint, where they are flammable.

Temperature of the material during machining reaches from 200 to 500ºC, depending on the type, cutting speed, and chip section. The role of MWFs fed into the workpiece is mainly to reduce mechanical and thermal load of the tool tip, to reduce internal and external friction, and thus to eliminate tool wear and prolong its durability. The lubricating effect of fluids is manifested through the creation of viable breaking film in fine cracks on the surface of the workpiece. The film facilitates deformation of the material in the construction of individual chip elements, which allows reduction of deformation work. To select the right MWFs it is necessary to apply, at the beginning of the process, machining operations require fluids with cooling and lubricating effect and, also at the end of the process, fluids with high lubricating effect. With increasing cutting speed and depth of cut, there are also pressure and temperature that increase in the cutting area and thus also the demands for processing fluids, especially for efficient heat dissipation. The selection of the most appropriate MWF for the intended use is described by certified metalworking fluid specialist (CMFS) Jerry Byers in [56] and [59].

The Possibility of MWF Determination and Exposure Assessment

Exposure to MWF mist in the work environment is generally assessed using one of three methods [49]:

- Integrated monitoring of all particles
- Integrated monitoring of specific components of MWF aerosols
- Direct measurement of total share of aerosols or selective measurement of aerosol fractions

MWF health risk is assessed either by the sum of aerosols and water vapour or solely by aerosols. The risk of inhalation of aerosols is caused by exposure to three agents: undiluted processing liquid, microbial contaminants, and other chemical contaminants accrued in MWFs during the process (e. g. toxic or allergenic elements from machined metal: Cr, Pb, Ni, Cd, etc.).

Weight concentration of oil mist gathered on the filter can be determined by gravimetry, but also by spectrophotometry (UV, IR). However, in all these methods the most important issue in determining the weight concentration of liquid aerosols is evaporation of liquid (water) from aerosols. During sampling this liquid is collected on a membrane filter and it changes its weight by flowing air. It is recommended to use the filter for the quantification of oil aerosols, but this one is reliable only for stable aerosols of water-insoluble MWFs. The problem of losing some oil vapor during sampling and other interferences in other methods is eliminated by the determination of individual aerosol fraction on the filter and by the addition of an adsorption filter (e. g. XAD2) to capture some oil fractions [35].

For the detection of water vapor and liquid aerosols at the same time a continuous measurement method [36] was developed which provides information about the size and distribution of aerosol particles divided into different factions in the impactor. Aerosol particles that are not captured in the impactor are transferred into the evaporator, where they are evaporated and subsequently analyzed by a serially connected flame ionization detector. By subtracting the measured value from the following fraction, the amount of MWF aerosols in a specific range of particle sizes is obtained. This method has been calibrated to di-2-ethylhexyl sebacate (DEHS). The overview of the most frequently used methods of sampling and determination of MWFs with a brief description is given in Table 2.

NIOSH Method 5524 [37]. The National Institute for Occupational Safety and Health (NIOSH) recommends exposure to MWFs to be limited by the value of 0.4 $mg \cdot m^{-3}$, measured as a thoracic fraction, or by the value of 0.5 $mg \cdot m^{-3}$, measured as an inhalable fraction, while both values are based on a reference time of 10 hours. Method 5524 for the sampling and analysis of MWF aerosols is a procedure that separates aerosol particles from

Table 2. Basic characteristic of the methods for determining MWFs.

Characteristic	Method			
	NIOSH 5524 [37]	HSE 84 MDHS [38]	OSHA ID-128 [39]	HSE MDHS 95/2 [40]
Sampler	TP[a)]: thoracic cyklone + PTFE filter (∅37 mm, MPD[c)] 2 μm), Total particulate: PTFE filter (∅37 mm, MPD[c)] 2 μm)	IF[b)]: Binder-free glass fibre filters or mixed cellulose ester membrane filters (MPD[c)] 0.8 μm)	IF[b)]: PVC filter (∅37 mm, MPD[c)] 5 μm)	IF[b)]: CME filter 0.8 μm, (Na or K used as marker) or filter from slicium fibers (B used as marker)
Flow rate	TP[a)]: 1.6 $l \cdot min^{-1}$, IP[b)]: 2 $l \cdot min^{-1}$	2 $l \cdot min^{-1}$, sampling time: 2 and 8 hours	1-2 $l \cdot min^{-1}$	2 $l \cdot min^{-1}$ sampling time: 2 and 8 hours
Measurement	gravimetry	gravimetry	Fluorescence spektrofoto-metry	ICP/AAS
Extraction	dichlormethane:methanol: toulene (1:1:1) methanol:water (1:1)	cyclohexane	chloroform, sodium chloride, sodium sulphate	
Balance sensitivity	0.001 mg	min. 0.01 mg	0.0001 mg	
Range	0.05 to 2 mg per sample		5-500 μg (LOD 1 $\mu g \cdot ml^{-1}$)	boron: 0.007 $\mu g \cdot ml^{-1}$, 0.024 $\mu g \cdot ml^{-1}$, sodium: 0.084 $\mu g \cdot ml^{-1}$, 0.28 $\mu g \cdot ml^{-1}$, potassium: 0.008 $\mu g \cdot ml^{-1}$, 0.028 $\mu g \cdot ml^{-1}$

[a)] thoracic particulate, [b)] inhalable particulate, [c)] MPD – mean pore diameter

admixed particles by extraction of a ternary mixture of dichloromethane, methanol, and toluene. This method is applicable to all types of processing fluids, if they are soluble in the extraction solvents.

HSE Method MDHS 84 [38]. Health and Safety Executive (HSE) published a method for the measurement of personal exposure to aerosols of mineral oils, which form the basis for MWFs. This method is suitable only for oil viscosities greater than 18 $mm^2 \cdot s^{-1}$ at 40ºC. Measurement of more volatile oil mist concentration with low viscosity can be underestimated in this method. If the total value of inhalable fraction is greater than 2.5 $mg \cdot m^{-3}$, the concentration of oil mist is detected by measuring filter weight after the extraction of oil in cyclohexane.

OSHA Method ID-128 [39]. The Occupational Safety and Health Administration (OSHA) defines permissible exposure limit of 5 $mg \cdot m^{-3}$ as a time-weighted average for 8-hour exposure to mineral oil mist, expressed as a total proportion of particles. Oil captured on filter was dissolved in chloroform and subsequently was compared with prepared oil standards by fluorescence spectrophotometry. The analysis consists of two parts: the selection of appropriate excitation wavelength and sample analysis by correct fluorescence wavelength.

HSE Method MDHS 95/2 [40]. For water-soluble MWFs there were no specific exposure limit values estimated. For water-soluble MWFs the Health and Safety Executive (HSE) set a recommended limit value of 1 $mg \cdot m^{-3}$. This value is only approximate and is not legally bound. The method involves the measurement of personal exposure to elemental markers of water-soluble MWFs using AAS or AES with inductively coupled plasma. The method is applicable if the machine oil sump includes an appropriate element with a sufficiently high concentration, which serves as a marker, for example Na, K, eventually B (inappropriate is the element that is contained in a metal workpiece, because it will be present in any particle formed during the metal machining process). Measured air volume is siphoning through a filter installed in the inhalation sampler and analyzed for the content of the marker along with a sample of fluid circulating in a machine, whose concentration is detected by refractometry.

Limits and Legislation of MWFs

Undiluted liquids contain a mixture of substances, but there are exposure limits only for some of them, e. g. mineral oil, ethanolamine, and diethanolamine.

From the viewpoint of the potential health risks assessment of metalworking machine operators, a liquid aerosol of MWF presents two different types of factors: chemical (harmful chemicals, e.g. mineral oils, alkanolamines, nitrosamines, volatile organic compounds, and others) and biological (bacteria, fungi, mould). The following parameters are considered:

a) Chemical composition of liquid aerosol
b) Time and method of exposure
c) Weight concentration and size of aerosol particles

The most significant routes of exposure are inhalation and dermal contact, which presents a minor pathway for the transfer of substances into the body. To determine the chemical composition of a liquid aerosol is quite a difficult task because, in addition to the basic ingredients (mineral, vegetable, animal or synthetic oil, diluted or undiluted with water), MWFs contain a range of additives that are added to processing fluids to improve their functional properties (e. g. emulsifiers, corrosion inhibitors, biocides, anti-odor and anti-foaming agents, stabilizers, etc.), but also contaminants acquired during handling of MWFs (e. g. particles of the workpieces/tool, running hydraulic or lubricating oil and also bacteria, fungi, and mould in the case of water-miscible MWFs, etc.).

To determine the value of the maximum permissible exposure limit (MPEL) to MWFs in relation to the specified reference period is therefore very difficult. In Slovak legislation MPEL is prescribed only for liquid aerosol (fumes) of mineral oil (averaged MPEL is 1 mg·m^{-3}, short-time MPEL is 3 mg·m^{-3}) [58]. Abroad only recommended limits (i. e. not legally bound) are set for MFWs, for example the NIOSH [37] limit for thoracic fraction is 0.4 mg·m^{-3} and the limit for total fraction is 0.5 mg·m^{-3}. Both values are related to the reference time of 10 hours.

There are no legally bound limit values for biological factors (e. g. mycotoxins and endotoxins from bacteria and fungi in MWFs).

Exposure to MWF Liquid Aerosols

Park et al. [41] performed an extensive study on exposure to MWF aerosol fractions (inhalable, thoracic, and respirable) as time-weighted arithmetic averages (TWA) by decades, industry type, depending on the operation and used MWF. They found a significant decrease in the level of weight concentration of MWFs during the decades from 1970 to 2000 as for total aerosol (average from 5.36 mg·m^{-3} to 0.55 mg·m^{-3}), as well for thoracic fraction (average from 0.48 to 0.40 mg·m^{-3}), but not for respirable fraction. They also found different exposures for different types of industries, but especially for the types of operations [42, 43], for example during grinding there were observed average exposures of 1.75 mg·m^{-3} compared to 0.95 mg·m^{-3} for other operations, and also for different types of MWFs: for pure oils 1.49 mg·m^{-3}, for soluble oil 1.08 mg·m^{-3}, for synthetic fluids 0.52 mg·m^{-3}, and for semi-synthetic fluids 0.50 mg·m^{-3}. According to the results of our measurements [54], during the turning process using the synthetic MWF there were detected concentrations of liquid aerosol in much wider range in the working atmosphere and it depended on:

1) The distance of the sampling head from the point of aerosol formation
2) Spindle speed
3) Fluid flow rate of MWF

Statistically designed experiments were performed [60] to determine the machining conditions that have the most significant effect on cutting fluid mist formation during a turning operation. Hwang and Chung [61] found that the rotational speed of the workpiece and the fluid flow rate have great influence on the aerosol diffusion rate in the turning operation. The interaction of the fluid with the rotating cylindrical workpiece during the turning operation is described in validated model for cutting fluid mist formation [62]. In machining operations performed with soluble oils, O'Brien et al. [63] measured 242 total aerosol mass concentrations ranging from 0.07 to 2.41 mg·m^{-3}. Simpson et al. [64] took 75 total inhalable particulate measurements where water-mixed MWFs were used. Concentrations varied from <0.01 to 1.82 mg·m^{-3} with a geometric mean of 0.07 mg·m^{-3}. Our exposure results [65] based on measurement were similar to the range of concentrations reported in the studies mentioned above.

By the evaluation of exposure to bioaerosols it was found that concentrations of microorganisms in the air varied from 1.2×10^1 to 1.5×10^5 CFU·m^{-3} (colony forming units·m^{-3}), while in the MWF samples we observed bacteria concentrations as high as 2.4×10^9 CFU·ml^{-1}. The endotoxins in the air varied from undetectable to 183 endotoxin units (EU)·m^{-3}, showing no correlation with the microorganisms in the air or with inhalable dusts. *Pseudomonas pseudoalcaligenes* was the most prevalent microbial species of considerable concentration [55].

The most abundant bacteria found on the culture media were isolated for several MWF samples. They were identified as *Mycobacterium* sp., *Shewanella putrefaciens*, *Pseudomonas putida*, *Pseudomonas stutzeri*, *Pseudomonas mendocina*, *Conamonas testosteroni*, *Stenotrophomonas maltophilia*, *Morganella moganii*, *Citrobacter freundii*, *Acinetobacter* sp., *Orchrobactrum* sp., *Brevundimonas diminuta*, and *Bacillus* sp. The mould identified by microscopic observation was the following: *Fusarium* sp. (with a median value concentration of 2.25×10^2 CFU·ml^{-1}), *Acremonium* sp., *Exophiala* sp., *Trichoderma* sp., and *Penicillium* sp. [55].

Strategy to Reduce the Exposure Effects of MWFs

Reducing the MWF effects in the work environment [51-53], is carried out by generally known principles of preventive medicine work:

a) By reducing the concentration (dose) and/or
b) By reducing exposure (duration, repetition, and frequency).

Technical and organizational (collective) actions are primarily applied. Technical actions include reducing the amount of MWFs, e. g. by technological change of process, more effective local exhaust or general room ventilation, substitution by less harmful substance or addition of anti-mist polymers [45], covering of the machine tool [46], and careful ongoing maintenance of equipment and process control. Organizational actions include: reducing the number of employees and their rotation at risk job, correct regime of work and relaxation (frequent breaks out of the risk areas), regular monitoring of pollutant concentration in the working environment, and performance of health surveillance, etc. Compensatory (individual) actions (e. g. use of personal protective equipment – breathing masks or respirators with an effective filter suitable for mist containing oil [44], gloves, goggles, etc.) are applied in the second place if there is no possibility to avoid exposure.

Environmental Aspects of MWF Use

Worldwide annual consumption of MWFs is estimated at more than 2×10^9 l. However, waste of used MWFs may be up to 10 times higher due to the fact that most MWFs must be diluted before use [47]. Used MWFs cause a high level of environmental contamination due to the presence of a complex mixture of several chemicals, which increases the demand on their final treatment or disposal. It is usually carried out by a combination of several physical and chemical methods, augmented by biological (biodegradation) methods [48], e.g. aerobic/anaerobic fluidized bed reactors/bioreactors with the use of a variety of fillings, media (sand, charcoal, peat etc.), or membranes. A detailed overview of the used and developed degradation methods with further references to the primary literature are in the review [47].

Conclusion

The general trend in the use of processing fluids is the transition from oil emulsions to fully synthetic water-miscible fluids. One of the possibilities of how to eliminate negative effects is the use of low-waste technology, where waste from machining is re-filtered, cleaned and re-used in the production process. However, such technologies are economically challenging and rarely used at the market, where the final price of the product is more decisive than environmental pollution. Therefore, the producers of MWFs try to eliminate unwanted additives and environmental pollutants from their recipes.

Our paper has presented several methods for measuring concentration of liquid aerosols emerging from MWFs in the workplace atmosphere. Human risks from metalworking machine operation and ways to reduce risk are assessed. The overview of degradation or disposal of used MWFs is presented from the viewpoint of ecological risk assessment.

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