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Review

The Occupational Exposure Limit for Fluid Aerosol Generated in Metalworking Operations: Limitations and Recommendations

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The aim of this review was to assess current knowledge related to the occupational exposure limit (OEL) for fluid aerosols including either mineral or chemical oil that are generated in metalworking operations, and to discuss whether their OEL can be appropriately used to prevent several health risks that may vary among metalworking fluid (MWF) types. The OEL (time-weighted average; 5 mg/m^3, short-term exposure limit ; 15 mg/m^3) has been applied to MWF aerosols without consideration of different fluid aerosol-size fractions. The OEL, is also based on the assumption that there are no significant differences in risk among fluid types, which may be contentious. Particularly, the health risks from exposure to water-soluble fluids may not have been sufficiently considered. Although adoption of The National Institute for Occupational Safety and Health's recommended exposure limit for MWF aerosol (0.5 mg/m^3) would be an effective step towards minimizing and evaluating the upper respiratory irritation that may be caused by neat or diluted MWF, this would fail to address the hazards (e.g., asthma and hypersensitivity pneumonitis) caused by microbial contaminants generated only by the use of water-soluble fluids. The absence of an OEL for the water-soluble fluids used in approximately 80-90 % of all applicants may result in limitations of the protection from health risks caused by exposure to those fluids.

Key Words: Metalworking fluid, Oil mist, Straight fluid, Water-soluble fluid, Metalworking operation

Introduction

Metalworking fluids (MWFs) are generally classified into four types (straight, soluble, synthetic and semi-synthetic) according to the amount and type of oil that they contain. They are extensively used in the metalworking industry to lubricate, cool the tool-workpiece interface, and remove debris from the work surfaces of metal parts that are being drilled, ground, milled, or turned in various metalworking operations such as cutting, grinding, and metal-forming.

MWFs have been the subject of a number of occupational epidemiologic studies of various types of cancer, non-cancerous respiratory conditions, and skin diseases [1-3]. In 1988, the National Institute for Occupational Safety and Health (NIOSH) concluded that substantial evidence exists for an increased risk of several cancer types (larynx, rectum, pancreas, skin, scrotum, and bladder) among workers exposed to MWFs prior to the mid-1970s [3]. However, an association between cancer type and risk from exposure to specific classes of MWFs was not discussed in detail [4]. To date, there have been occupational exposure limits (OEL) established for mineral oil (straight fluid) only, in spite of the fact that an increased risk for several cancer types, respiratory diseases and skin disorders was found to be associated with the water-soluble fluid types, including

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semi-synthetic and synthetic fluid [1-3]. The specific MWF type associated with an increased risk of various cancer types or other health conditions remains to be determined.

The aim of this review was to assess current knowledge related to the OEL for fluid aerosols including oil generated in metalworking operations, and to discuss whether the current OEL can be appropriately used to associate the several health risks that may vary among fluid types. To achieve this aim, both the basic characteristics of MWFs used in various operations and the historical changes in establishment of the OEL were summarized. In addition, the relationships between total (or inhalable) and thoracic fractions of airborne MWF reported so far were reviewed.

Methods

This study was conducted through an extensive review of the literature. Literature review techniques were used to find relevant articles in the industrial hygiene and epidemiologic literature. Keyword search terms including 'metalworking fluids', 'machining fluids', 'cutting oil', 'oil mist', 'mineral oil mist', 'coolants', 'metalworking operation', 'machining operation', and 'metal removal operation', were used singly and in combination.

Major aspects reviewed were the basic characteristics of MWF, historical changes in the OEL for fluid aerosol or oil mists, and the relationship between the total (or inspirable) and thoracic fraction of fluid aerosols. First, the physical and chemical characteristics associated with metalworking operations were reviewed and classified by fluid type to indicate which operation characteristics should be specific to fluid-type. These basic characteristics were used to establish whether health risk may differ among fluid types and among operations wherein a specific fluid-type is used. Second, the change to the OEL for aerosols generated in metalworking operations was summarized through review of the Threshold Limit Value (TLV) recommended each year by the American Conference of Governmental Industrial Hygienists (ACGIH), and the Occupational Exposure Standards and Workplace Exposure Limits (WEL) reported in the United Kingdom (UK). Third, the results of studies conducted by a number of authors up to the end of 2010 examining the relationship between the total (or inspirable) and thoracic fractions in fluid aerosols were also analyzed. Fourth, the fluid aerosol measurements reported from metalworking operations were summarized and re-analyzed to examine the relationship between the total and thoracic fractions in fluid aerosols.

Results

General characteristics by MWF type

MWFs provide lubricating and cooling effects that are essential to the economical production of precisely-machined and ground parts. The type and degree of lubrication and the degree of cooling required for various metalworking operations vary according to the kind of operation, the rigidity of the part and its fixturing, the type of metal and its hardness and microstructure, the total material and its geometry and the speed, feed, and depth of cut selected [5], which ultimately determine the selection of fluid-type in operation plants [6,7]. The basic characteristics of the four fluid types are summarized below.

Straight fluid

This group comprises mineral (most common), vegetable, animal, and marine oils with no water content; petroleum-based oils may be severely hydrotreated or severely solvent-refined to reduce the polynuclear aromatic hydrocarbon content. They are composed primarily of mineral oils but may also contain a wide range of components, including chlorinated paraffins, tricresyl phosphate, and sulfur compounds, among many others [8]. They are used without dilution, "as they come from the drum", and provide the greatest lubricating (and the poorest cooling) properties [5]. In addition, they have the advantages of resistance to biological degradation, and good rust protection.

Soluble fluid

These are composed of a base of petroleum or mineral oil combined with emulsifiers and blending additives [5]. They are referred to as emulsions or emulsifiable oils. They provide lubricity (reduction of friction) and cooling capacity, however, their cooling properties are not as strong as those of the chemical fluids (synthetic and semisynthetic) [9].

Semi-synthetic fluid

These are essentially a hybrid of soluble and synthetic oils, combining the advantages of both soluble oils (forgiving performance, good corrosion control and lubricity,) and synthetic oils (clean, and good biological control) [10]. They have the advantage of strong cooling capacity, average lubricity and longer sump life [9].

Synthetic fluid

These have no mineral oil content, and are a mixture of organics and additives to provide lubricity and corrosion prevention. They have 70-95% water content. They are synthetic since they contain no mineral oil, are the best at heat removal and are very clean. They have excellent cooling and rust protection properties compared to soluble oils in grinding operation. Formulas are usually transparent when mixed, so they provide good visibility for grinding operations and enclosed machines [10]. As mentioned above, the oil is of two kinds, mineral or synthetic. Mineral oils are napthenic and paraffinic hydrocarbons refined from natural crude oil. Specific formulations and their contents differ not only between fluid types, but also from manufacturer to manufacturer, depending on the purpose for which the fluid is intended. Through use, fluids may become contaminated from the materials (metals) being worked upon, from machine and hydraulic oils, microbial growth, chemical reactions between components and through thermal degradation, which may also be specific to fluid-type [3]. It may be extremely difficult to recognize all components, by-products and contaminants.

Straight vs water-soluble fluids

In broad terms, there are essentially two types of MWF: oil-based (straight) and water-soluble (soluble, synthetic and semi-synthetic). Oil-based MWFs are still the fluid of choice for certain metalworking applications, although they are less popular than they were in the past. Water-mixed fluids may also contain alkanolamines, boron compounds and emulsifiers as well as ionic and nonionic surfactants, which are not contained in straight fluids. In addition, in order to control microbial growth, biocides are added (either originally or during use) only to water-soluble MWFs, which provides an excellent environment for microbial growth [3]. Each component of MWF may contribute to health effects, and hence the nature and severity of any health effects depends to some extent on the specific composition of the MWF [11,12] and the specific metalworking operation in which the fluid is applied. The complexity of the MWFs themselves and the various operations in which they are used makes it difficult to differentiate the type and abundance of specific MWF components, not only within a specific fluid but also among the four fluid types. At minimum, however, exposure specific to any of the four fluid types, or to the two broad fluid types (oil and water-soluble fluid), should be assessed.

Historical OELs for mineral oil mist

Historical change to the OELs for aerosols including mineral oil mists are summarized in Table 1. An OEL of 5 mg/m^3 TLV-time weighted average (TLV-TWA) and a 10 mg/m^3 short-term exposure limit were used for oil-mist based MWFs prior to 1998, when NIOSH suggested a recommendes exposure limit [3]. This OEL has been used as the limit to assess exposure for all four fluid types, since there has been no specific OEL found for each fluid type [13]. Since 1985, a number of North American researchers have evaluated the association between worker exposure to MWFs and cancer mortality or respiratory morbidity, and reported a significant association of exposure to MWF with risk of several cancer types. The United Auto Workers petitioned the Occupational Safety and Health Administration (OSHA) in 1993 to establish a new standard of 0.5 mg/m^3 for MWF aerosols, regardless of the mineral oil content [14]. In response, NIOSH examined the potential carcinogenicity of MWF through a review of all relevant literature reported up to 1997, and offered a recommended exposure limit (REL) of 0.5 mg/m^3 for the total and 0.4 mg/m^3 for the thoracic particulate mass to protect against the adverse respiratory health effects of MWF exposure [3]. These figures were to apply to all types of MWF, based on an assumption that there are no significant differences in risk among the various fluid types [3,15,16]. In 1987, The International Agency for Research on Cancer designated untreated and mildly-treated mineral oil as a Group 1 carcinogen (carcinogenic to humans) based on its association with squamous cell carcinoma of the skin, and sinonasal and bladder cancer [17].

In 2001, for the first time, ACGIH noticed the intended changes (NIC) of TLV-TWA only for oil mist (mineral) of 0.2 mg/m^3 measured as inhalable aerosol, and provided carcinogenicity designations according to the level of refining for mineral oil: A2-Suspected Human Carcinogen for “poorly and mildly refined”, and A4-Not Classifiable as a Human Carcinogen for “highly and severely refined”. From 2010, the ACGIH NIC was withdrawn. Instead, highly and severely refined mineral oil excluding metal working fluids was set at 5 mg/m^3 and poorly and mildly refined mineral oil, excluding metal working fluids, was classified as suspected carcinogen (A2). There has been no ACGIH-TLV to assess exposure to aerosols including mineral oil and bioaerosols generated in various metalworking operations [18].

Since publication of the NIOSH MWF REL [3], neither the OSHA nor ACGIH has recommended an exposure limit for water-soluble MWF specifically, other than their previous exposure limits for mineral oil.

In 2002, the UK Health and Safety Executive suggested guidance values for MWF of 3 mg/m^3 for oil-based and 1 mg/m^3 for water-soluble, both measured as inhalable aerosols, although these guidance values, unlike the UK occupational exposure standards, are not regulated limits but are given as a recommendation to workplaces. These guidance values were partly derived from exposure to neat oil-based and water-soluble fluid assessed at 31 UK engineering companies [19]. The

Table 1. Changes in occupational exposure limits for mineral oil mist

Organization	Year	Occupational exposure limit	Fluid type*	Size fraction
American Conference for Governmental Industrial Hygienists	1964-2008	TWA 5 mg/m^3, STEL 10 mg/m^3	Oil mist	Total
	2008-2009	TWA 5 mg/m^3, STEL 10 mg/m^3	Oil mist Withdraw adopted	Total
	2001-2005	TWA 0.2 mg/m^3 as NIC	Mineral oil	Inhalable
	2006-2008	TWA 0.2 mg/m^3 as NIC	Mineral oil used in metalworking	Inhalable
	2009-2010	TWA 5 mg/m^3 as NIC	Mineral oil -pure, highly and severely refined mineral oil	Inhalable
	2010-2011	TWA 5 mg/m^3	Mineral oil, excluding MWFs -pure, highly and severely-refined mineral oil	Inhalable
	2001-2008	A2 (suspected carcinogen) as NIC	Mineral oil used in metalworking -poorly and mildly-refined mineral oil	NA
	2009	A2 (suspected carcinogen) as NIC	Mineral oil - poorly and mildly refined mineral oil	
	2010-2011	A2 (suspected carcinogen)	Mineral oil, excluding MWFs -poorly- and mildly-refined mineral oil	NA
Occupational Safety and Health Administration, USA	1964-2007	TWA 5 mg/m^3, STEL 10 mg/m^3	Mineral oil	Total
	1998	SAC recommend adoption of REL 0.5 mg/m^3	All types	Total
National Institute for Occupational Safety and Health, USA	< 1998	TWA 5 mg/m^3, STEL 10 mg/m^3	NI	Total
	1998	REL 0.5 mg/m^3	All types	Total
		REL 0.4 mg/m^3	All types	Thoracic
Health Safety Executive, UK	1990s-2007	TWA 5 mg/m^3, STEL 10 mg/m^3	Oil mist	Total
	2002	ACTS guidance values		
		TWA 3 mg/m^3	Oil-based (neat oil)	Inhalable
		TWA 1 mg/m^3	Water-soluble	Inhalable

TWA: time weighted average, STEL: short term exposure limit, MWF: metalworking fluid, REL: recommended exposure limit, SAC: Standard Advisory Committee, ACTS: Advisory Committee on Toxic Substances, NIC: notice of intended change, NI: no information, NA: not applicable.
*Oil mist & mineral oil: oil-based (straight) MWF, water-soluble MWF: soluble, synthetic and semi-synthetic.

UK guidance value of 1 mg/m^3 inhalable aerosol for water-soluble fluid would range between approximately 0.3 mg/m^3 and 0.5 mg/m^3 total aerosol, based on the relationships reported in the literature [20-22], which is similar to the NIOSH REL (0.5 mg/m^3) [3]. As of 2007, there have been no WELs for not only mineral oil mists, but also for water-soluble MWFs.

Trends in fluid aerosol level by fluid type [23,24]

Park et al. [23,24] conducted an extensive MWF-related literature review of studies prior to the 1970s through to 2007 and identified aerosol levels measured in the process using MWFs. All personal or area aerosol levels were calculated as weighted arithmetic means (WAMs). The aerosol AMs were multiplied by the number of measurements, summed, and divided by the total number of measurements to derive the WAMs. The WAMs of total and thoracic aerosol level reported by Park et al. [23,24] were re-summarized by fluid type used in the process using MWF (Tables 2, 3). The details of literature review and data analysis were described elsewhere [23,24]. Those studies found significant differences in WAMs for total aerosol among fluid types and industry types. The overall WAM for straight oil aerosols (1.49 mg/m^3) was significantly higher than that for water-soluble fluid aerosols (0.92 mg/m^3, p = 0.002). Significant differences in thoracic exposure levels were not found among the fluid types and industry type (Table 3).

The relationship between thoracic and total fluid aerosol concentrations

In 1998, NIOSH recommended a REL for MWF of 0.4 mg/m^3 of thoracic particulate matter, corresponding to a total par-

Table 2. Comparison of weighted arithmetic means (WAMs) for total metalworking aerosol by decade, industry, operation and fluid type (excerpt from references [23,24])

Decade	Industry type	Operation type	Fluid type	Number of measurements	WAM (mg/m^3)	SD (mg/m^3)	Multiple mean comparison test*	p-value
All	All	All	Straight	1,406	1.49	1.45	a	0.017
All	All	All	Soluble	2,233	1.08	1.50	NS	
All	All	All	Synthetic	321	0.52	0.14	b	
All	All	All	Semi-synthetic	551	0.50	0.20	b	
All	All	All	Water-soluble	3,105 (2,233 + 321 + 551)	0.92	1.30	b	
All	Auto	All	All	1,775	1.47	1.10	a	< 0.001
All	Autopart	All	All	1,126	1.83	3.16	a	
All	Small jobs	All	All	4,751	0.68	0.84	b	
All	All	All	All	9,379	0.94	1.41		

SD: standard deviation, NS: no statistically significant differences with any other groups.
*Multiple mean comparison t-test; different letters indicate significant differences, †Analysis of variance (dependent variable = log-transformed value).
The number of measurements across subcategories may not equal the total number of measurements for any particular category because means are not presented when information on a subcategory was not provided.

Table 3. Weighted arithmetic means (WAMs) of thoracic fraction by industry and fluid type (excerpt from references [23,24])

Classification		Number of samples	WAM (mg/m^3)	SD (mg/m^3)
Industry	Auto	4,788	0.46	0.18
	Auto part	439	0.35	0.07
	Small jobs	1,384	0.32	0.07
	Steel	20	0.34	0.01
Fluid	Straight	1,599	0.46	0.17
	Soluble	1,810	0.43	0.2
	Synthetic	758	0.4	0.05
	Semisynthetic	55	0.38	0.09
All	All	6,631	0.43	0.17

SD: standard deviation.
The number of measurements across subcategories may not equal the total number of measurements for any particular category because means are not presented when information on a subcategory was not provided.

ticulate matter figure of 0.5 mg/m^3. Since devices to measure the thoracic fraction are not yet widely available, a conversion factor of 1.25 (0.5 mg/m^3 of total = 1.25 × 0.4 mg/m^3) or 0.8 (0.4 mg/m^3/0.5 mg/m^3 = 0.8) was offered to estimate the thoracic fraction from total aerosol concentration [3]. Since NIOSH first made the recommendation for the conversion factor, a total of four studies have examined the relationship between total and thoracic fraction aerosols measured by paired-samples in metalworking plants (Table 4) [21,25-27].

The present study re-analyzed both the total (or inspirable) and thoracic fraction concentrations obtained by Park et al. [23,24] and found that several conversion factors obtained from various plants (Table 4) were far higher than the NIOSH conversion factor of 1.25, which was derived from data measured from automobile plants only.

Piacitelli et al. [27] performed a two-parameter linear regression comparing results obtained from the 238 paired personal thoracic and total particulate samplers in 79 machine shops composing 23 two-digit Standard Industrial Classification codes. Based on all paired samples, the mean ratio of total to thoracic aerosol was 1.82 for the total mass concentration and 1.92 for the extractable fraction [27]. Verma et al. [26] found that the ratio ranged from 1.42 to 1.67 in steel tube making and automotive component manufacturing plants. In the same plants, a lower ratio (1.38) was later reported [21]. These values were obtained from the facilities, where synthetic and semi-synthetic fluids were used predominantly. Reh et al. [25] first studied the ratios of total to thoracic fraction among fluid types based on exposure of 147 workers to the four fluid types at a plant that produced air compressors (synthetic = 1.61, soluble = 1.67, straight = 1.5, semi-synthetic = 1.51). No substantial difference was shown among fluid types, or among types of operation and industry.

The ratio of total to thoracic aerosol levels estimated from total and thoracic aerosol levels reviewed from pre-1970 to 2008 by Park et al. [23,24], was also much higher than those reported by not only the previous studies (Table 4), but also by NIOSH (Table 5).

Discussion

Most studies reviewed in this work used the OEL and TLV for MWF, which are applicable only to mineral oil-based straight fluid and not to the other three water-soluble fluids, while the OEL for water-soluble fluids used in the UK has been recommended by Stear [19]. ACGIH applied the characteristics of particular metalworking operations to introduction of the TLV, although it had been on the NIC list from 2001 to 2010 [18]. The absence of an OEL for water-soluble MWF, as well as a lack of consideration for different particle-size fractions, may not address the protection from health risks that may vary among fluid types.

A number of epidemiological studies have assessed the relationship between exposure to fluid types and cancer risk [2,4,29-37]. A cancer risk from synthetic and soluble fluids cannot be ruled out, since an increased risk for cancer of the esophagus, liver, and prostate for synthetic fluids [38], and breast cancer for soluble fluids [2] has been reported. The health effects

Table 4. Relationship between total (or inspirable) and thoracic fraction levels

Aerosol fraction sampler		Industry type	Operation type	Fluid type	Number of samples	Sampling method	Ratio (X/Y)	Reference
Total mass (X)	Thoracic (Y)							
Inhalable (two-stage impactor)	Thoracic sampler	Auto	Grinding and various machining	Straight, soluble and synthetic	403	P and A (21)	1.25	*[3]
37-mm closed filter cassette	Thoracic sampler	Small machine shops	Grinding and various machining	Straight, soluble, synthetic	238	P	1.8	[27]
Inhalable (two-stage impactor)	Thoracic sampler	Auto	Grinding and various machining	Straight, soluble, synthetic			1.4	[41]
37-mm closed filter cassette	Thoracic sampler	NI	49 operations	Straight, soluble, synthetic, semi-synthetic	147		1.51-1.67	[25]
37-mm closed filter cassette	Thoracic sampler	Auto and steelmaker		Soluble, semi-synthetic	122		1.39	[21]
Inhalable (three-stage impactor)		Autopart	NI	NI	37	A	1.38	[26]

NI: no information, P: personal sampling, A: area sampling, *based on the study by Woskie et al. (1994) [28]

Table 5. Relationship between total (or inspirable) and thoracic fraction levels

Aerosol fraction sampler		Industry type	Operation type	Fluid type	Number of samples*	Sampling method	Ratio (X/Y)*	Reference
Total mass (X)	Thoracic (Y)							
Filter cassette, impactor	Thoracic sampler	Auto	All operations	All type	1,775(total), thoracic (4,788)	B	3.19 (1.47/0.46)	Park's study based on [23,24]
Filter cassette, impactor	Thoracic sampler	All industry	All operations	All type	9,379(total), 6,631 (thoracic)	B	2.18 (0.94/0.43)	Park's study based on [23,24]

B: personal and area.
*Number of samples and ratio were from Tables 2, 3.

associated with exposure to the more recently-developed water-soluble fluids such as synthetic and semi-synthetic fluids are not yet fully understood [26]. The risk that each fluid type poses to workers may vary due to various degrees of refining, recycling, improperly reclaimed chemicals, different degrees of chemical impurity, and chemical reactions between components [3]. Therefore, an OEL that is applicable to all types of fluids without consideration of size characteristics, and which is based on the assumption that there are no significant differences in risk among fluid types, could be contentious. These reasons for this are expanded on below.

First, the OEL that does not sufficiently take into account the effect of exposure to water-soluble fluids, and so may not protect against the health effects that may be primarily caused by use of those fluids. New contaminants such as microbes, nitrosamine and tramp oils that may be generated when water-soluble fluids are used could lead to development of respiratory diseases. A single OEL for MWF is also not feasible because subsequent exposure to used water-soluble fluids that become contaminated with microbial agents and other unwanted substances such as tramp oil make the MWF too heterogeneous to assign a single OEL [15]. Although adoption of the NIOSH REL for MWF (0.5 mg/m^3) would be an effective step towards minimizing and evaluating the upper respiratory irritations that may be caused by neat or diluted MWF [3], this would fail to address the hazards (e.g., asthma and hypersensitivity pneumonitis) caused by microbial contaminants specifically generated by use of water-soluble fluids [15]. NIOSH has also admitted that some workers have developed work-related asthma, hypersensitivity pneumonitis, or other adverse respiratory effects when exposed to water-soluble fluids at lower concentrations [3]. Because of the potential for microbial contamination of MWF, even if exposure is kept below the REL this may not protect workers against some of the most serious complaints and illnesses associated with MWF exposure [15]. Stear [39] also shared our concern that the OEL for mineral oil mist only may no longer be representative of modern machining practices.

Second, the major component of the NIOSH REL (0.5 mg/m^3) that can be converted into the thoracic fraction could also be questioned. The NIOSH standard of 0.4 mg/m^3 for thoracic particulate mass is intended to prevent upper respiratory tract health effects [3]. The conversion ratios reviewed here were found to be consistently higher than that (1.25) of NIOSH. This result is in agreement with the observation that the NIOSH conversion factor is not universal, which has been pointed out in a number of studies examining the relationship between the total and thoracic fractions [21,25-27]. We found that the conversion factors can vary among not only industry types and operation types, but also fluid types, resulting in a lack of consistency (Tables 4, 5). It is well known that MWFs are used in many types of metalworking operations, wherein diverse aerosol size characteristics are found, and different fluid types are used. Furthermore, MWFs at a plant were selected according to the type of operation being performed, the material being machined, and the machine used [6,7], which could influence the risk that may vary among fluid and operation types. Therefore, the health risk may depend on not only fluid type, but also the operation, if a type-specific fluid is used. The conclusion from our review is that the NIOSH conversion factor could be conservative. Thus, if total fluid aerosol exposure is at or below 0.5 mg/m^3, then although the REL of 0.4 mg/m^3 as the thoracic fraction is likely to be met, the actual thoracic exposure cannot be assessed from the total particulate matter measurements. It is accepted that knowledge of the relationships among the various MWF aerosol fractions would be highly useful information for assessing data of MWF airborne exposure based on different aerosol fractions, and for interpreting occupational exposure standards based on different fractions, if these values were proven to be appropriate [21]. However, it seems to be very difficult to arrive at a universal thoracic conversion factor that can take into account the four different fluid types, the accessibility of sampling and analytical methods and protection from adverse health effects. It is recommended to directly measure worker exposure to thoracic fluid aerosols [25,26], rather than implementing a conversion factor. To derive a useful conversion factor to estimate fluid size fractions, more metalworking operations of a greater variety should be studied.

Third, the effects of fluid type on aerosol exposure levels were reported to be different elsewhere, even when they vary among the type of operation. Woskie et al. [28] found that straight oil aerosol exposure levels were significantly higher than those from water-soluble fluids for not only large particles (> 9.8 μm), but also for the respirable aerosol fraction level.

Experimental studies have found straight oils resulted in higher aerosol levels [40], but among the water-miscible fluids, the findings have again been inconsistent [41]. This finding was also confirmed through literature review conducted by Park et al. [23,24]. In general, total aerosol exposure levels from straight oils were generally higher than those of other fluid types. Higher aerosol levels may be generated from straight oils because they are 100% oil, as opposed to water-soluble fluids, which have far less oil and more water [40]. Because the water is lost to evaporation, these fluids produce smaller aerosols and may result in lower exposure levels [42]. Straight oils also may be associated with high aerosol levels because these oils may be used more frequently in older machines that may be less likely to have exposure control measures. Other contributors to the inconsistent results may be other fluid components, contamination by other particles in the workplace, volatility [42], age, temperature [40], and tramp oil level [41]. If aerosols levels in the process using MWF are different, the question of whether the same OEL could be applied to all type of MWF needs to be discussed.

Finally, as the use of water-soluble fluids including synthetic and semi-synthetic fluids has increased, compared with the use of straight fluid, specific measures to prevent health effects caused by the use of water-soluble fluids, such as the establishment of an OEL for them, should be introduced. Water-soluble MWFs, including soluble, synthetic and semi-synthetic fluids, are now used in approximately 80-90 % of all applications [43]. Production timing and volume of the various fluid types has changed over time in response to changes in (or demands of) metalworking operations. Straight fluids were the most-produced type of MWF until around the mid-1940s (53-83% of all fluid production), but their production volume has steadily decreased since the 1950s (25-40% in the 1950s and 1960s and < 10% in the 1990s) [43]. Their decline was matched by an increased production of the other three water-soluble fluids. In particular, semi-synthetic fluids contributed < 10% of the output in the 1960s, but over the following decades their production rose until the 1990s, when they constituted about one-third of all fluids produced. Water-soluble fluids may replace straight oils and eliminate the associated environmental issues of oil mist, slippery floors and fire hazards, while providing similar or improved lubricity compared to straight oils [10].

Conclusion and Recommendations

The four types of MWF, straight, soluble, synthetic and semi-synthetic, have different chemical ingredients. Changes in the composition of fluids over time may have been driven by the need to improve performance. It is likely that the occupational health risks caused by the use of MWF vary depending on not only the type of process and fluid, but also the operation environment in which they are used. The OEL has only been applicable to straight MWF, without consideration of different particle-size fractions. Further study may be considered not only to develop dual OELs for prevention of health risk caused by use of water-soluble fluids, but also to determine how fluid-type may be associated with those health risks.

Conflict of Interest

No potential conflict of interest relevant to this article was reported.

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