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Sistematski pregled rizika po zdravlje ljudi povezanih sa izloženošću fluidima za obradu metala

Luka Latinović¹, Marjan Marjanović²

¹School of Engineering Management, University Union - Nikola Tesla, Belgrade, Serbia, luka.latinovic@fim.rs

²Clinic for General, Visceral and Thoracic Surgery - InnKlinikum, Altötting, Germany

Apstrakt: Fluid za obradu metala (engl. *Metalworking fluid* - MWF) naziv je za niz ulja, emulzija i drugih fluida koji se koriste u procesima obrade metala radi smanjenja trenja, toplote, rđe i evakuacije opiljaka. Međutim, većina ovih fluida zasniva se na ograničenom resursu - mineralnom ulju i sadrži biocide što predstavlja opasnost po životnu sredinu u svakoj fazi životnog ciklusa, počevši od ekstrakcije resursa pa sve do odlaganja. Osnovni metodološki pristup ovog istraživanja zasnovan je na sistematskom pregledu relevantne akademske literature u oblasti zdravstvenih rizika povezanih sa primenom MWF. Akademskom elektronskom izvoru literature poslali su upiti za odgovarajuće termine, dok je pretraživač podešen da sortira rezultate opadajućim redosledom, prema relevantnosti. Na osnovu sistematskog pregleda literature, ova studija je identifikovala i zabeležila 31 izveštaj iz recenziranih naučnih časopisa, relevantan za rizike po zdravlje ljudi povezane sa izloženošću MWF. Većina ovih studija su studije serije slučajeva i kros-sekcijske studije od kojih je 13 ustanovilo povezanost izloženosti MWF sa malignim bolestima; 7 sa respiratornim bolestima; 6 kožnim bolestima ili alergijama, i 7 sa patogenim mikrobnim kontaminatima. Najznačajnije studije identifikovale su povećanu incidenciju malignih oboljenja, uključujući rak pluća, jetre, kože, pankreasa i ždrela kod kohorti radnika izloženih MWF. Uz to, uspostavljena je i jaka povezanost sa astmom i hipersenzitivnim pneumonitisom. Istraživanje nije vršilo kategorizaciju rezultata prema formulaciji MWF, kao ni prema načinu primene.

Ključne reči: MWF, fluidi za obradu metala, biocidi, zdravstveni rizici, opasnost na radu.

A Systematic Review of Human Health Risks Associated with Metalworking Fluids Exposure

Abstract: Metalworking fluid (MWF) is the name given to a range of oils, emulsions and other fluid used in metalworking processes to reduce friction, heat, rust, and evacuate swarf. However, most of these fluids are based on finite resource - mineral oil and contain biocides, thus representing an environmental threat at each life cycle stage from resource extraction to disposal. The basic methodological approach of this research was based on the systematic review of relevant academic literature in the field of health issues caused by MWF application. An academic electronic reference source was queried for the related terms while search engine was set to sort the results by relevance. Based on the systematic literature review, this study has identified and noted 31 reports in the peer reviewed literature directly relevant to human health risks associated with MWF exposure effects. The majority of these studies were case series and cross-sectional studies of which 13 addressed malignant diseases; 7 respiratory effects; 6 skin effects or allergies; and 7 pathogenic microbial contaminants. The major studies identified excess malignant diseases including lung, liver, skin, pancreatic, and laryngeal cancer in cohorts exposed to MWF. In addition, a strong association has been established with asthma and hypersensitivity pneumonitis. The research did not categorise the results according to the MWF formulation, nor according to the method of application.

Keywords: MWF, metalworking fluids, biocides, biocide-free, health risks, occupational hazard.

1. Introduction

Metalworking fluids (MWFs) are fluids used in several industrial metalworking processes such as forming (Bay, 2010), cutting (Weinert et al., 2004), and grinding (Brinksmeier et al., 1999). On account of their beneficial tribological characteristics, MWFs help in dissipation and conduction of heat, and in reduction of temperature in metalworking processes by reducing friction between tool and workpiece. This paper regards metalworking fluids as liquids supplied to a manufacturing process in a way that allows for increased productivity based on lubricating and cooling effects (Brinksmeier et al. 2015). MWFs are formulated as either straight-oils (mineral oils), synthetic (without oils), or as a soluble (mineral oil emulsions), combined with surfactants and other additives (Skerlos et al., 2008). Over 2 billion litres of oil-emulsion and straight-oil MWFs are used each year worldwide in manufacturing processes (Skerlos et al., 2008). Two major application methods in machining processes are either by pouring on the workpiece, as a liquid that leaks slightly, or in the form of a spray, which is more efficient. When sprayed, part of MWF becomes aerosolised, generating airborne particulate matter (PM) at concentrations up to two orders of magnitude higher than allowable by e.g., the US ambient air pollution standard (Costello et al., 2020). Today, the primacy in industrial use holds emulsions consisting of mineral oil, *aqua* and additives (Fig. 1).

Figure 1. MWF market share by type of formulation (Bhattacharya & Senapati, 2017)

These emulsions are prone to biological infestation and thus have to be preserved by the addition of biocides harmful to health by causing numerous health issues. Some MWF constituents are carcinogenic in animals, including N-nitrosamines found in water-based synthetic fluids, and some polycyclic aromatic hydrocarbons (PAH) found in the oil-based fluids. Efforts to reduce exposures to these potentially carcinogenic MWF have been ongoing for decades (Costello et al., 2020). There are many epidemiological studies associating MWFs with numerous human health concerns such as respiratory and skin diseases for workers (Geier et al., 2004; Suuronen et al., 2007), malignant diseases (Costello et al., 2011), and other health issues. Furthermore, oil-based MWFs have to be viewed critically not only from the perspective of being hazardous towards the human health, but also from the environmental perspective. They are based on finite resource – crude oil, and represent an environmental threat at each life cycle stage from resource extraction to disposal. This is a serious issue that has to be addressed with due care (Latinović, 2019; Garaplija, 2020).

Based on the systematic literature review, this paper examines and summarises the most significant research on human health risks associated with MWF occupational exposure and classifies them into four main groups based on the established risks. The aim of this research is to raise risk awareness and encourage current employers and employees to pay due attention to the observance of prescribed procedures and safety measures, as well as to encourage manufacturers and producers to understand competitive advantages of “green marketing” (Čalasan et al., 2021), thus to develop and resort to alternative MWFs such as e.g., glycerol-based MWF (Latinović 2021).

2. Methods

The basic methodological approach of this research is based on the systematic review of relevant academic literature in the field of health effects caused by MWFs application. Google Scholar

academic electronic reference source was queried for the terms ‘metalworking fluids’, ‘machining fluids’, ‘cutting fluids’, ‘cutting oils’, ‘MWF’ combined with the term ‘health’. The search engine was set to sort the results by relevance. This manuscript reviewed results of 10 consecutive result pages per query. Items returned were reviewed for relevance to MWFs health risks on human. The relevant literature was classified based on the established risk to human health, while documented risks were divided into four main groups, namely: malignant disease, respiratory diseases, skin diseases and allergies, and microbial-induced risks, presented in the Table 1, 2, 3, 4 respectively. The review noted 31 reports in the peer reviewed literature directly relevant to MWF exposure effects. Of these, 13 addressed malignant diseases; 7 respiratory effects; 6 skin effects or allergies; and 7 microbial contaminants. It should be noted that although malignant melanoma e.g., belongs also to skin diseases, on account on its malignancy it was classified in malignant diseases. Several papers established correlation of MWF application with several health issues such as respiratory and skin diseases, thus were presented both in Table 2 and Table 3.

3. Results

The tables 1, 2, 3, and 4 present the key findings on the health risks associated with MWF exposure such as malignant diseases, respiratory diseases, skin diseases and allergies, and microbial-induced health risks, respectively.

Table 1. The relevant literature on malignant diseases associated with MWFs exposure, in ascending order by date

Reference	Health risk
Park et al. (1988)	Stomach cancer, rectal cancer
Silverstein et al. (1988)	Gastrointestinal malignancies, pancreatic cancer
Eisen et al. (1992)	Skin and laryngeal carcinoma
Calvert et al. (1998)	Larynx, rectum, pancreas, skin, scrotum, and bladder cancer associated with at least some MWFs used prior to the mid-1970s.
Mirer (2003)	Elevated risk ratios for stomach cancer, and cancer at other sites
Savitz (2003)	Rectal cancer, laryngeal cancer
Agalliu et al. (2005)	Prostate cancer
Thompson et al. (2005)	Female breast cancer
Malloy et al. (2006)	Rectal cancer
Betenia et al. (2012)	Cervical cancer
Costelo et al. (2011)	Malignant melanoma
Shrestha et al. (2016)	Renal cell carcinoma
Park (2018)	Larynx, esophagus, brain, female breast, and uterine cervix cancer
Costello et al. (2020)	Most notably skin and breast cancer, but also esophageal, liver, pancreatic, and prostate cancer

Table 1 presented the findings on the correlation between MWF exposure and malignant diseases. The least recent of these studies, by Park et al. (1988), identified digestive cancer excesses among workers in a ball bearing plant exposed to cutting fluids. Standardized proportional mortality and mortality odds ratio studies were carried out, and cause of death and work histories were obtained for 702 of 768 hourly employees with ten or more years’ service who died between 1969 and 1982. The major findings were significant excesses in proportional mortality ratios (PMR) from stomach cancer (PMR = 2.0) and rectal cancer (PMR = 3.1) among white men. After control for age at death, there was a significant association between stomach cancer and precision grinding exposures, consisting primarily of direct contact with water-based cutting fluids (usually emulsified oils) and their aerosols. The pattern of stomach cancer was consistent and suggested an association with the soluble oil cutting fluids (Park et al., 1988).

In the same year, another epidemiological study (Silverstein et al., 1988) also reported associations between gastrointestinal cancer mortality and exposure to cutting fluids and abrasives in metal machining and precision grinding operations. This study reported similar findings in a third and larger population. Cause of death and work histories were determined for 1,766 bearing plant workers who died between Jan 1, 1950 and June 30, 1982. Mortality odds ratios (SMOR) and proportional mortality ratios (PMR) revealed significant excesses of gastrointestinal malignancies (Silverstein et al., 1988). The authors concluded that their study have confirmed previous evidence that grinding operations using water-based cutting fluids increase the risk for stomach cancer and provides moderate evidence that exposures to straight oil-cutting fluids increase the risk for cancer of the pancreas (Silverstein et al., 1988).

Based on the magnitude and precision of results, and the monotonic exposure-response gradient, Savitz (2003) found strong evidences for association between exposure to straight metalworking fluid and rectal cancer, with a relative risk of 2.0 in the uppermost exposure category. A much weaker association was found with soluble metalworking fluids and essentially no indication of an association with synthetic metalworking fluids (Savitz, 2003). It should be noted that the author also found that the risk for rectal cancer was greatest for workers hired before 1970, and suggested that most probably changes in the constituents of straight metalworking fluids subsequent to that time, changed the association with rectal cancer (Savitz, 2003).

In the research by Betenia et al. (2011), a cohort of 4374 female autoworkers was followed from 1985-2004 for cancer diagnosis. Based on an elevated standardized incidence rate (SIR), the authors focused on cervical cancer in an internal analysis. Results based on 40 cases, the SIR was statistically significantly elevated for both race specific subgroups: 3.30 and 2.43, respectively for Caucasian and African American women. The standard mortality ratio (SMR) was also statistically significantly elevated for Caucasian women (3.44) based on seven observed deaths. Relative risks for soluble and synthetic MWF and nitrosamines were modestly elevated but not statistically significant and there was no association with oil-based straight fluid, thus the authors concluded that water-based MWF may play a role in the aetiology of cervical cancer (Betenia et al., 2011).

Costelo et al. (2011) followed a cohort of autoworkers from 1985 through 2004 for cancer incidence. The authors estimated hazard ratios in Cox models for cumulative exposure to total particulate of straight fluid (neat oil), soluble fluid (oil emulsified in water), and synthetic fluid (no oil). On the basis of 76 incident cases of malignant melanoma in the cohort of 14,139 white males, the results showed hazard ratios of 1.99 (95% confidence interval = 1.00—3.96) for the highest category of straight fluid. Risk was greatest in the most recent time window. Penalized splines suggested a linear exposure-response over the full range of exposure. Results for soluble fluid were more modest. There was no association with synthetic fluid. The results provided evidence, based on quantitative measures of metalworking fluid, that oil-based fluid, particularly straight mineral oils are associated with the incidence of malignant melanoma (Costelo et al., 2011).

Table 2 addresses another major MWF associated occupational health hazards, namely respiratory diseases, such as hypersensitivity pneumonitis, asthma etc.

Table 2. The relevant literature on respiratory diseases associated with MWFs exposure, in ascending order by date

Reference	Health risk
Gupta & Rosenman (2006)	Hypersensitivity pneumonitis
Rosenman (2009)	Asthma, hypersensitivity pneumonitis
Burton et al. (2012)	Asthma, bronchitis, breathing difficulties, irritations, hypersensitivity pneumonitis, impaired lung function
Fornander et al. (2013)	Upper airway symptoms caused by airborne irritants
Barber et al. (2014)	Hypersensitivity pneumonitis
Park (2019)	Asthma and hypersensitivity pneumonitis
Nett et al. (2020)	Asthma and hypersensitivity pneumonitis

In the most recent research by Nett et al. (2020), five cases of a severe and previously unrecognized lung disease characterized by B-cell bronchiolitis and alveolar ductitis with emphysema (BADE) were identified among workers at a machining facility that used MWFs, although MWF exposure could not be confirmed as the aetiology. In the United Kingdom e.g., MWF is now the predominant cause of occupational hypersensitivity pneumonitis (HP) (Gupta & Rosenman, 2006; Rosenman, 2009; Barber et al., 2014; Nett et al., 2020).

Under continuous conditions associated with respiratory disease outbreaks, over a working lifetime of 45 years, workers exposed to MWF at 0.1 mg/m³ are estimated to have a 45.3% risk of acquiring HP or occupational asthma under outbreak conditions and a 3.0% risk assuming outbreak conditions exist in 5% of MWF environments.

In addition to respiratory outcomes, skin diseases such as allergic and irritant contact dermatitis (Table 3) persist as frequent causes of occupational disease following MWF exposure.

Table 3. The relevant literature on skin diseases and allergies associated with MWFs exposure, in ascending order by date

Reference	Health risk
De Boer et al. (1983)	Contact dermatitis
Geier et al. (2004)	Contact dermatitis
Suuronen et al. (2007)	Contact dermatitis
Henriks-Eckerman et al. (2008)	Presence of allergens in MWFs
Hannu et al. (2012)	Allergic contact dermatitis, irritant contact dermatitis
Nett et al. (2020)	allergic and irritant contact dermatitis

Skin diseases and allergies are the most frequent causes of occupational health issues associated with MWF exposure (Nett et al., 2020). Fortunately, the consequences are not as severe as is the case with malignant diseases.

Finally, the last category addresses microbial contaminants found in MWFs (Table 4) on account of their potential pathogenicity.

Table 4. The relevant literature on microbial contaminants found in MWFs, in ascending order by date

Reference	Microbial species and health risks
Wallace et al. (2002)	Mycobacterium immunogenum associated with hypersensitivity pneumonitis
Awosika-Olumo (2004)	Enterobacteriaceae, Flavimonas, Gram-positive rods, and Sphigomonas
Bakalova et al. (2007)	Stenotrophomonas sp., Micrococcus sp., Agrobacterium sp., Bacillus sp.
Cyprowski et al. (2007)	Shewanella putrefaciens, Bacillus sp., Staphylococcus warneri, Acremonium butyri, Acremonium strictum and others
Tillie-Leblond et al. (2010)	Mycobacterium immunogenum
Perkins & Angenent (2010)	Alcaligenes faecalis, Ochrobactrum anthropi, Pseudochrobactrum asaccharolyticum, Brevundimonas diminuta, Wautersiella falsenii, Morganella morganii
Murat et al. (2011)	Mycobacterium immunogenum
Kapoor & Yadav (2012)	Mycobacterium abscessus

Epidemiological and clinical studies suggest that both chemical ingredients and microbiological contaminants in MWF may also cause various respiratory symptoms and diseases (Suuronen et al.,

2007; Henricks-Eckerman et al., 2008). A microbial contaminant, namely Nontuberculous mycobacteria (NTM) have been associated with hypersensitivity pneumonitis in machinists. *Mycobacterium immunogenum* and *Mycobacterium chelonae*, have been reported thus far to have the ability to colonize contaminated MWFs (Falkinham, 2002). In the research by Kapoor & Yadav (2012), the third species was isolated, namely *Mycobacterium abscessus*. It is a species distantly related to the ones that cause tuberculosis and leprosy, part of a group known as rapidly growing mycobacteria and is found in water, soil, and dust (CDC, 2021). It has been known to contaminate medications and products, including medical devices. When skin is infected with *M. Abscessus*, it usually exhibits classic inflammatory symptoms such as *rubor*, *tumor*, and *dolor*. Infected areas can also develop boils or pus-filled vesicles. Other signs of *M. abscessus* infection are fever, chills, muscle aches, and a general feeling of illness (CDC, 2021).

Other microbiological contaminants referenced in the Table 4 also cause a variety of health problems, some of which are less dangerous and some potentially fatal.

4. Discussion

4.1 Principal findings

This study has identified and noted 31 reports in the peer reviewed literature directly relevant to MWF exposure effects, from which the most notable studies were also summarised. The majority of these studies were case series and cross-sectional studies from the USA, and UK, of which 13 addressed malignant diseases; 7 respiratory effects; 6 skin effects or allergies; and 7 microbial contaminants. The most commonly affected workplaces were large car-manufacturing plants, ball-bearing plants and other plants where metal machining is one of the main technological processes. Health risks associated with MWF exposure were identified with several types of MWFs, mostly straight oil, and soluble water-based oil emulsions. Risks and health problems range from mild to potentially fatal. Potentially fatal health problems include some high-probability fatal ones, such as most malignancies. Microbial contamination with bacteria, opportunistic mycobacteria, and fungi was also included because prevention of these contaminants is the main and only reason why biocides are a constituent of almost all commercial MWFs.

However, stabilizing biocide concentration due to water evaporation is also challenging, while different species react specifically to different biocides. Finally, adding biocides helps in prevention of microbial contamination but on the other hand, induces elevated risks of other health hazards presented in tables 1, 2, and 3, some of which are malignant. Furthermore, spraying method of applying MWFs on working piece increased efficacy and reduced its consumption, but on the other hand, induced elevated risks of respiratory diseases by creating aerosolised mist. This is a *circulus vitiosus* which has to be broken in order to provide workers with a healthier working environment.

4.2 Recommendations for further research

Metal machining is an indispensable set of technological processes in a large number of industries, wherein at the current stage of the technology used, MWFs are necessary. Environmental health & safety departments are responsible for standard operating procedures and management of fluids, and the transfer of information regarding policy and procedure to their employees. However, not all shops have the resources required to develop and implement the proper standard operating procedure, nor all the employees adhere to them. Furthermore, MWF represent an environmental threat at each life cycle stage from resource extraction to disposal, making metal swarf recycling economically unfeasible, while increasing workpiece cleaning expenses. Thus, it is necessary to find sustainable MWF formulations, which implies using renewable feedstock with less or no harm towards the environment or human health. Although this might seem as a distant goal, several researchers proposed and examined potential MWF alternatives, from which the most promising is a glycerol-based MWF (Winter et al., 2012; Wichmann et al., 2013; Latinović, 2021).

Glycerol-based MWFs have several advantages over oil-based MWFs. Firstly, they are made of renewable resource – vegetable glycerol, the main by-product of biodiesel production, eliminating the need for finite resource – crude oil. Moreover, glycerol is virtually non-toxic, water soluble compound (Tan et al., 2013), which facilitates workpiece cleaning after processing and enables metal swarf recycling. Furthermore, glycerol-based MWFs exhibited adequate tribological and corrosion inhibition

characteristics in the machining phase, although further research is still needed (Latinović, 2021). Finally, probably the most important advantage is the biostatic property of glycerol. If glycerol concentration is sufficient (>40%) in the MWF solution, no additional biocides are needed (Winter et al., 2012; Wichmann, 2013).

4.3 General limitations of the review

Given the comprehensive nature of the search terms and the search strategy employed, it is possible that reports from other investigations could have been missed. Furthermore, the review did not take into account the change in MWF production technology over time nor did it divide the results according to the type of MWF whose use was associated with increased health risks. The relevancy of some studies is such that they were taken into account and presented in the research; beside they are dating from 1988. Although their main focus was on straight mineral oil, which today does not have the major market share (Fig. 1), the chosen methodological approach for this research was based on the relevancy so they had to be included.

Due to the types of studies summarized in this review, the evidence is mostly correlative and based on epidemiological studies, and reflects the constraints placed on reactive health investigations as opposed to planned research studies. The findings from this literature review are predominantly from cross-sectional surveys of workplaces and case series of workers with disease, with little data from case-control studies. It is possible therefore that some of the cross-sectional outbreak studies may have underestimated, by studying a survivor population, or overestimated the size of the problem.

5. Conclusion

Exposure to MWF represents a significant health risk for the employees who deal with the daily tasks involving metal machining and MWFs. Based on the findings, four major health risk groups were established, namely: malignant diseases; respiratory diseases; skin diseases and allergies, and microbial contaminants with pathogenic potential.

Three major studies identified excess cancer including lung, liver, pancreatic, laryngeal, and leukaemia associated with MWF exposures. Reports also strengthened associations of asthma and hypersensitivity pneumonitis with recent exposure to MWF. Skin diseases, allergies as well as pathogenic microbiota are also associated with MWFs. Nevertheless, these fluids are as dynamic as the formulations themselves (complex & dynamic). This paper did not quantify the risks depending on the type of MWF, the method of use, and the type and time of exposure.

The aim of the paper was to raise awareness of the existence of the health and environmental problem and provide a basis for further research, especially in the direction of finding alternative MWFs. However, until the widespread use of commercially viable and sustainable MWFs is achieved, it is crucial that awareness of proper standard operating procedures is shared with everyone involved with MWF use in order to provide proper MWF management and reduce human health and environmental risks.

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