

Evaluating Workers' Exposure to Metalworking Fluids and Effective Factors in Their Dispersion in a Car Manufacturing Factory

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Introduction. Metalworking fluids (MWFs), which are widely used in metalworking operations, can cause different adverse effects, e.g., dermal and respiratory disorders, and cancer. Evaluating workers' exposure to MWF mists and the effective factors in their dispersion were the purpose of this study. **Materials and Method.** Seventy-five out of 300 workers working in metalworking workshops were randomly selected. MWF concentrations were measured with the National Institute for Occupational Safety and Health (NIOSH) 5524 method. Air temperature and velocity were also determined as the predicted effective parameters on the level of exposure. **Results.** The results indicated that exposure to MWF mists in one workshop was higher than in the other ones ($p < .05$). The findings also showed that temperature was an effective factor in the dispersion of MWF mists ($p < .05$). **Discussion.** The exposure of almost all workers was under the threshold limit value of 5 mg/m^3 , but it was over the value recommended by NIOSH of 0.5 mg/m^3 . Air temperature was an effective factor in workers' exposure ($r = .576$).

metalworking fluid occupational exposure temperature air velocity total mist, thoracic mist

1. INTRODUCTION

Metalworking fluids (MWFs) are used in metalworking operations for cooling and lubricating [1, 2, 3, 4, 5, 6, 7]. Car manufacturing is an industry in which workers are exposed to these chemicals, due to metalworking operations. Since MWFs consist of different chemical compounds, e.g., chlorides, phosphates, nitrates, ethanol amines and bio-acids, which are used in producing MWFs, workers may be exposed to those compounds and show related side effects [1, 4, 7, 8, 9, 10]. Dermal and respiratory disorders, and

cancer are the most frequently reported side effects of exposure to MWFs [11, 12, 13, 14].

A study on 766 dead workers who had at least 10 years' work history with MWFs found that the mortality rate from lung cancer was twofold higher than the expected rate [15]. Also, another part of that study, which was done on 350 stone workers who had been exposed to MWFs for 8–10 h a day, found that lung cancer was 1.20 and respiratory diseases were 1.35 times over the expected rates [15]. Other studies also recognized MWFs as a factor for rapid development of pulmonary pnomopathy or other respiratory diseases [16, 17, 18]. Eshraghi

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[19] and Eisen, Smith, Kriebel, et al. [20] showed that the prevalence of pulmonary disorders was higher than the expected amounts among turners. Another study showed that machine workers' exposure increased nasal and throat symptoms, cough, wheezing, breathlessness and asthma even in environments with exposure levels below the current occupational exposure limit for oil mists [21].

During metal machining, the rotating machine tool or grinding wheel generates fine droplets and vapor, which can cause occupational health problems [22]. Different factors, including the spinning rate of tools, type of machineries, controlling measures, and maintenance of machineries, can influence the emission of MWFs in the environment. Regarding the extensive use of MWFs in industries and, as a result, exposure of a large number of workers to their mists, and also regarding their effects on health, this study was designed and implemented to (a) evaluate the exposure of workers in a car-manufacturing factory to MWFs, (b) examine the effects of factors, such as season and job type on their exposure to MWFs and (c) examine the effects of factors, such as type of machineries, temperature and air velocity, on the emission of MWFs.

2. MATERIALS AND METHODS

This cross-sectional study was performed in a car-manufacturing factory. It took place in metal-working workshops producing trimmer cylinders, trimmer cylinder heads, and Danobat cylinders and cylinder heads. Cylinders and cylinder heads are parts of car engines. These workshops use a large amount of water-soluble MWFs, which contain water, emulsifiers, biocides, mineral oils, etc. Workers' exposure to MWFs was evaluated with the National Institute for Occupational Safety and Health (NIOSH) 5524 method [23].

Following a pre-test, and considering the obtained means and *SDs*, and statistical methods, 75 subjects were randomly selected for the study out of 300 workers: 119 from the workshop producing trimmer cylinders, 99 from the one producing in trimmer cylinder heads, and 82 from the workshop producing Danobat cylinders and cylinder heads.

To sample total (inhalable) mists, 37-mm Teflon filters with 2- μ pore size (made by SKC, UK), two-piece 37-mm closed-face holders, personal sampling pumps (model 224-PCXR 3, SKC) calibrated with an automatic calibrator were used. To sample thoracic mists, a nylon personal cyclone was also used in addition to the aforementioned equipment. This tool segregates thoracic mist from total mist. The concentration of thoracic mist was calculated with Equations 1–2. The results of the pre-test showed that contaminant concentrations were nearly the same during the whole shift. Sampling duration was established at 3–4 h.

For personal sampling, a sampling train was attached to the subjects. After sampling, the filters were transferred to a laboratory. They were put in desiccators for 2 h, then in a balance room for 1 h. After that, they were weighed with a Sartorius 22D scale (Germany, 0.0001 precision).

In the next step, MWF was extracted with a triple solution (toluene, methanol and dichloromethane with 1:1:1 voluminal proportion) and a double solution (deionized water and methanol with 1:1 voluminal proportion). After drying the filters under laboratory hoods for 2 h, they were weighed. Then, exposure to MWFs and suspended particles was calculated with the equations of the NIOSH 5524 method:

$$C_T = \frac{(W_2 - W_1) - (B_2 - B_1)}{V} \times 1000, \quad (1)$$

$$C_{MWF} = \frac{(W_2 - W_3) - (B_2 - B_3)}{V} \times 1000, \quad (2)$$

where W_1 , W_2 = weight of filter, before and after sampling, respectively, mg; W_3 = weight of filter after extraction, mg; B_1 , B_2 = weight of control filter, before and after sampling, respectively, mg; B_3 = weight of control filter after extraction, mg; C_T = concentration of suspended particulates, mg/m³; C_{MWF} = concentration of MWF mists, mg/m³; V = volume of sampled air, L.

A thermal anemometer model TA4 (Korea) was used to measure air temperature and velocity.

Statistical analysis of the data was done with SPSS version 11; *t* test (when the sample size

seemed low, Mann–Whitney nonparametric test), analysis of variance (ANOVA), regression and Pearson correlation coefficient were used to analyse data.

3. RESULTS

Figure 1 compares the level of workers’ exposure to suspended particulates and MWF mists. It shows that ~80% of exposure involved MWF mists.

Results of workers’ exposure (based on Scheffe’s test) showed that workers in the workshop producing trimmer cylinder heads had different exposure to inhalable and thoracic MWF mists

compared to those in the Danobat workshop ($p < .05$). Workers in the Danobat workshop and workers in the workshop producing trimmer cylinders had similar exposure to inhalable and thoracic MWF mists ($p > .05$), as did workers in the workshops producing trimmer cylinders and trimmer cylinders ($p > .05$).

Figure 2 shows that exposure to MWF mists was lowest in the Danobat workshop and highest in the workshop producing trimmer cylinder heads.

Table 1 shows that workers’ exposure to inhalable and thoracic MWF mists was similar in spring and summer ($p > .05$). Results of the nonparametric Mann–Whitney test confirmed the t -test results.

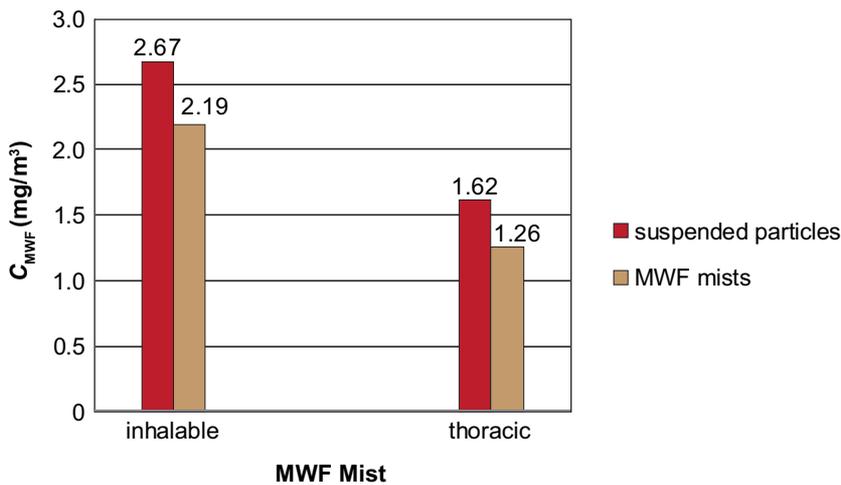


Figure 1. Exposure to metalworking fluid (MWF) mists and to suspended particles. Notes. C_{MWF} = concentration of MWF mists.

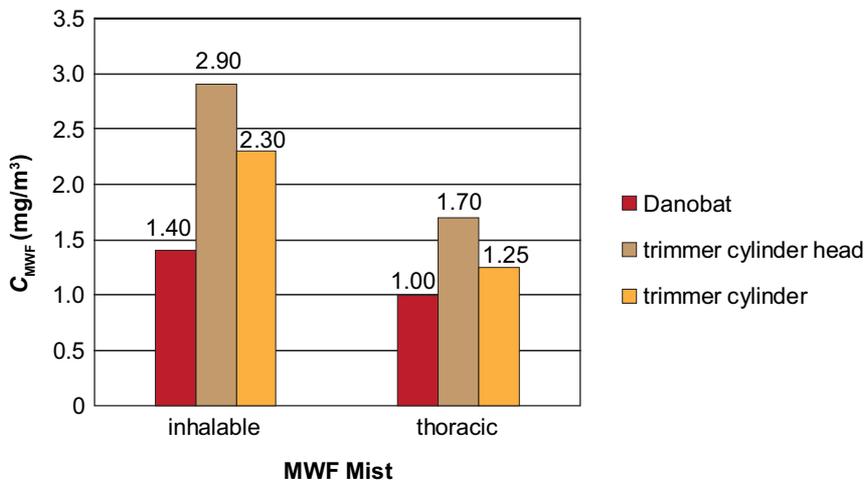


Figure 2. Exposure to metalworking fluid (MWF) mists by workshop. Notes. C_{MWF} = concentration of MWF mists; Danobat = workshop producing Danobat cylinders and cylinder heads; trimmer cylinder head = workshop producing trimmer cylinder heads; trimmer cylinder = workshop producing trimmer cylinder workshop producing trimmer cylinder.

Table 2 shows that workers' exposure to inhalable and thoracic MWF mists was similar in different jobs ($p > .05$). Results of the nonparametric Mann–Whitney test confirmed the t -test results.

The correlation test between exposure to inhalable and thoracic MWF mists and temperature

showed a significant relation between them ($r_1 = .572, r_2 = .660$), but air velocity did not have a significant effect on exposure to inhalable mists ($r_1 = .283, p > .05$), whereas it had a significant effect on exposure to thoracic MWF mists ($r_2 = .373, p < .05$). Table 3 and Figures 3–4 show the respective results.

TABLE 1. Exposure to Metalworking Fluid (MWF) Mists (mg/m^3) by Season, M (SD)

| MWF Mists | Spring | Summer | p |
|-----------|--------------------------|--------------------------|------|
| Inhalable | 2.24 (0.88) ^a | 2.15 (1.38) ^b | .820 |
| Thoracic | 1.12 (0.02) ^c | 1.40 (0.83) ^d | .152 |

Notes. N = number of samples; a = $N = 16$, b = $N = 22$, c = $N = 17$, d = $N = 20$.

TABLE 2. Exposure to Metalworking Fluid (MWF) Mists (mg/m^3) by Job, M (SD)

| MWF Mists | Workers | Supervisors | p |
|-----------|--------------------------|--------------------------|------|
| Inhalable | 2.19 (1.20) ^a | 2.10 (1.23) ^b | .970 |
| Thoracic | 1.31 (0.67) ^c | 1.08 (0.33) ^d | .410 |

Notes. N = number of samples; a = $N = 3$, b = $N = 35$, c = $N = 6$, d = $N = 31$.

TABLE 3. Correlation Between Exposure to Metalworking Fluid (MWF) Mists (Dependent Variables) and Temperature and Air Velocity (Independent Variables)

| MWF Mists | Air Velocity | Temperature |
|------------------------|--------------|-------------|
| Inhalable ($N = 38$) | | |
| r | .283 | .572 |
| p | .085 | <.001 |
| Thoracic ($N = 37$) | | |
| r | .373 | .660 |
| p | .023 | <.001 |

Notes. r = Pearson correlation coefficient; N = number of samples.

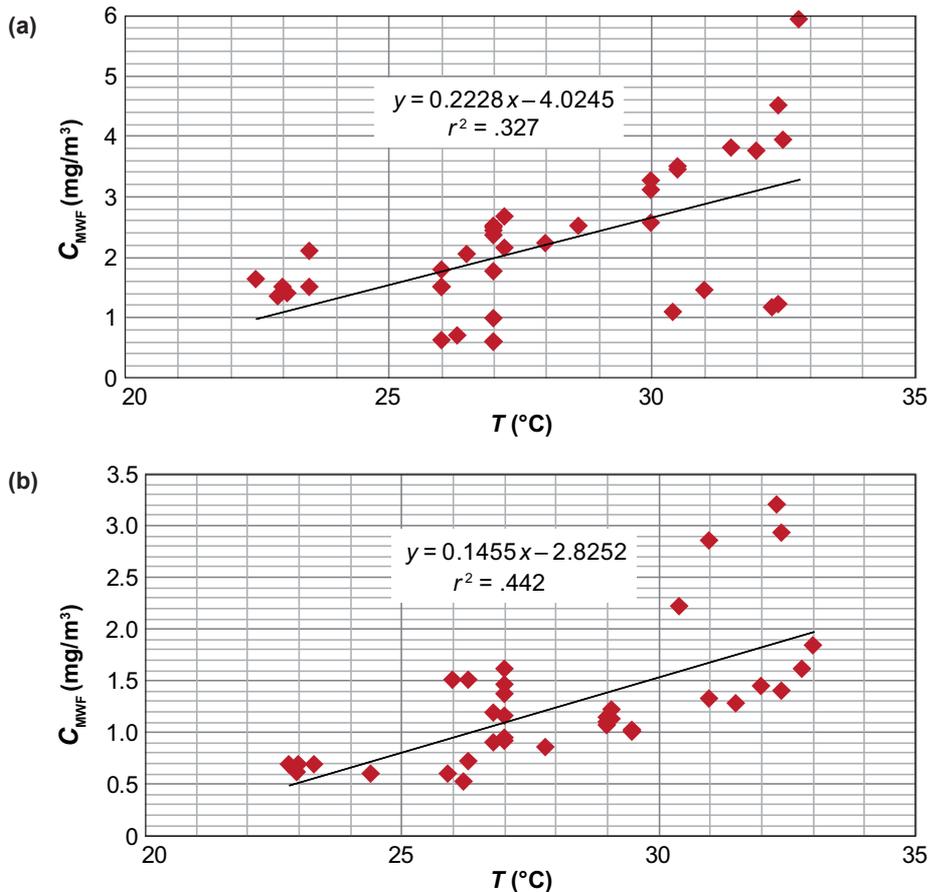


Figure 3. Temperature (T) and exposure to (a) inhalable and (b) thoracic metalworking fluid (MWF) mists. Notes. C_{MWF} = concentration of MWF mists; $x = T, y = C_{\text{MWF}}$.

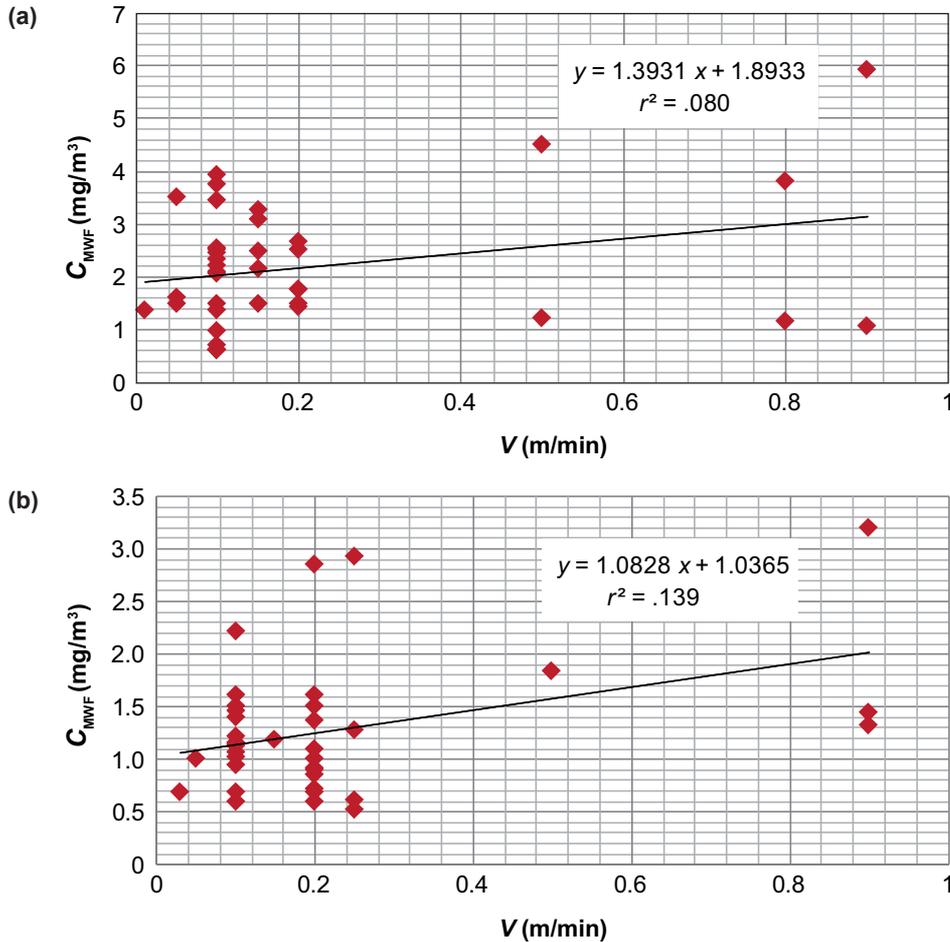


Figure 4. Air velocity (V) and exposure to (a) inhalable and (b) thoracic metalworking fluid (MWF) mists. Notes. C_{MWF} = concentration of MWF mists; $x = V$, $y = C_{MWF}$.

4. DISCUSSION

The results showed that workers' exposure to inhalable and thoracic MWF mists was 2.20 and 1.26 mg/m^3 , respectively, which was under the 5- mg/m^3 8-h time weighted average. However, workers' exposure exceeded the recommended values of 0.5 and 0.4 mg/m^3 for inhalable and thoracic mists, respectively. The measured concentrations were higher than those found by Simpson (<1 mg/m^3) [24] and Reh, Harney, McCleery, et al. (<1 mg/m^3) [25]. Fallah Vadeghani found similar results in a study on exposure to MWF mists in a polishing factory [26]. According to Park, Stewart and Coble, by 1999, exposure to this pollutant decreased to ~0.50 mg/m^3 , i.e., under the mean exposure in the present study [27].

Exposure to MWFs was lowest in the Danobat workshop (1.46 and 0.82 mg/m^3 for inhalable and thoracic mists, respectively), and highest in the workshop producing cylinder heads (2.93 and 1.59 mg/m^3 for inhalable and thoracic mists, respectively). Automation of the process and doing similar work for a shorter time (thus using less MWFs), as well as enclosing the process and installing a local ventilation system, are among the effective factors resulting in an almost two-fold reduction in MWF mist dispersion and exposure in the Danobat workshop compared to the workshop producing trimmer cylinder heads workshop for inhalable and thoracic MWF mists. Installing the ventilation system in the trimmer cylinder workshop resulted in lower exposure compared to the workshop producing trimmer cylinder heads (~0.77 and 0.82 mg/m^3 for inhalable

and thoracic mists, respectively), but higher compared to the Danobat workshop (~1.5 times for inhalable and thoracic mists), as a result of a process that was not enclosed and a different type of ventilation system. These findings are similar to those of Piacitelli, Sieber, O'Brien, et al. They found that using ventilation and automated systems, and enclosing the process, played an important role in controlling the emission of this pollutant and reducing workers' exposure [15].

Piacitelli et al.'s study on workers in a turning workshop with different jobs found that some workers had more exposure to MWF mists [15]. But since MWF mists were relatively homogeneously dispersed in all working environments of our study and, as a result, all the workers in various jobs had similar exposure to MWF mists, our results were different from those of Piacitelli et al.

The results showed that air temperature had an important effect on the emission of MWF mists in the working environment ($p < .05$). It seems that temperature can cause higher evaporation of the compounds of MWF, and condensation of vapours due to temperature gradient in other parts of the workshops can produce mists of the pollutant. The equation of regression line are given by $C_{MWF} = -2.8252 + 0.1455 T$ for thoracic mists and $C_{MWF} = -4.0245 + 0.2228 T$ for inhalable mists (where T = temperature, °C); they have the correlation coefficient of .660 and .572 respectively. The results and the related correlation coefficients showed that controlling the temperature in plants at 20–30 °C, could reduce exposure to MWF mists by 30%–40%.

Air flow in workshops can take mists far away the hoods of a ventilation system and scatter them to other parts of the workshops. Therefore, even though air velocity does not have any significant effect on workers' exposure to MWF mists ($p > .05$), but regarding the correlation coefficient and Figure 4, it is expected that by controlling air velocity at workshops to under 1 m/min, exposure to MWF mists can be reduced by 6%–8%. Concentrations of thoracic and inhalable MWF mists can be estimated with the respectively equations: $C_{MWF} = 1.078 + 1.3931 V$ (correlation coefficient of .373) and $C_{MWF} = 1.8933 + 1.3931 V$ (correla-

tion coefficient of .283), where V = air velocity, m/min. On the other hand, since workers' exposure was similar in spring and summer, it is obvious that despite of the presence of doors, windows and a ventilation system, the atmospheric conditions of workshops are not considerably influenced by the outside environment, and this can be regarded in controlling the atmospheric condition of workshops to control the level of exposure.

This study showed that ~80% of particle pollutions of metalworking operations of the car-manufacturing industry were related to MWFs. So, controlling the emission of MWF mists is important in reducing the particle pollution of the workshops. The other 20% of the pollution is from the other kinds of particles of metalworking operations, and dust entering through doors and windows. Some methods, such as ventilation, enclosing the process, lowering the temperature in the workshop, etc., can be useful in reducing the emission of these pollutants into the working environment and in reducing workers' exposure to such pollutants.

REFERENCES

1. American National Standards Institute. Mist control considerations for the design, installation, and use of machine tools using metalworking fluids (Standard No. ANSI B11.TR2-1997). New York, NY, USA: ANSI; 1997.
2. Ball A. A survey of metalworking fluid mist in manufacturing plants. *Lubrication Engineering*. 1997;53(9):18–22.
3. Balms JR. Surveillance for occupational asthma. *Occup Med*. 1991;6(1):101–10.
4. Bruce RW. CRC handbook of lubrication: theory and practice tribology. Vol. 1–2. Boca Raton, FL, USA: CRC Press; 1988.
5. Friesen MC, Costello S, Eisen EA. Quantitative exposure to metalworking fluids and bladder cancer incidence in a cohort of autoworkers. *Am J Epidemiol*. 2009;169(12):1471–8. Retrieved June 2, 2014, from: <http://aje.oxfordjournals.org/content/169/12/1471.long>.
6. Costello S, Friesen MC, Christiani DC, Eisen EA. Metalworking fluids and

- malignant melanoma in autoworkers. *Epidemiology*. 2011;22(1):90–7.
7. Stear M. Metalworking fluids—clearing away the mist? *Ann Occup Hyg*. 2005;49(4):279–81. Retrieved June 2, 2014, from: <http://annhyg.oxfordjournals.org/content/49/4/279.long>.
 8. Thorne PS, Adamcakova-Dodd A, Kelly KM, O’Neill ME, Duchaine C. Metalworking fluid with mycobacteria and endotoxin induces hypersensitivity pneumonitis in mice. *Am J Respir Crit Care Med*. 2006;173(7):759–68. Retrieved June 2, 2014, from: <http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2662953/>.
 9. Henriks-Eckerman ML, Suuronen K, Jolanki R. Analysis of allergens in metalworking fluids. *Contact Dermatitis*. 2008;59(5):261–7.
 10. Zeka A, Kriebel D, Kennedy SM, Wegman DH. Role of underlying pulmonary obstruction in short-term airway response to metal working fluid exposure: a reanalysis. *Am J Ind Med*. 2003;43(3):286–90.
 11. Eisen EA, Holcroft CA, Greaves IA, Wegman DH, Woskie SR, Monson RR. A strategy to reduce healthy worker effect in a cross-sectional study of asthma and metalworking fluids. *Am J Ind Med*. 1997;31(6):671–7.
 12. Forbes JD, Markham TN. Ann Arbor case reports. Cutting and grinding fluids in chronic pulmonary airway disease. *J Occup Med*. 1967;9(8):421–3.
 13. Kennedy SM, Greaves IA, Kriebel D, Eisen EA, Smith TJ, Woskie SR. Acute pulmonary responses among automobile workers exposed to aerosols of machining fluids. *Am J Ind Med*. 1989;15(6):627–41.
 14. Krzesniak L, Kowalski J, Droszcz W, Piotrowska B. Respiratory abnormalities in workers exposed to oil mist. *Eur J Respir Dis Suppl*. 1981;62(113):88–9.
 15. Piacitelli GM, Sieber WK, O’Brien DM, Hughes RT, Glaser RA, Catalano JD. Metalworking fluid exposures in small machine shops, an overview. *AIHAJ*. 2001;62(3):356–70.
 16. Li K, Aghazadeh F, Hatipkarasulu S, Ray TG. Health risks from exposure to metal-working fluids in machining and grinding operations. *International Journal of Occupational Safety and Ergonomics (JOSE)*. 2003;9(1):75–95. Retrieved June 2, 2014, from: <http://www.ciop.pl/6144>.
 17. Gordon T. Metalworking fluid—the toxicity of a complex mixture. *J Toxicol Environ Health A*. 2004;67(3):209–19.
 18. Rosenman KD. Asthma, hypersensitivity pneumonitis and other respiratory diseases caused by metalworking fluids. *Curr Opin Allergy Clin Immunol*. 2009;9(2):97–102.
 19. Eshraghi A. The survey of the relationship between worker’s health and environmental factors in the metalworking, assembly and compressed air small shops [Master of Science in Public Health thesis]. Tehran, Iran: Tehran University of Medical Science; 1983. In Persian.
 20. Eisen EA, Smith TJ, Kriebel D, Woskie SR, Myers DJ, Kennedy SM, et al. Respiratory health of automobile workers and exposures to metal-working fluid aerosols: lung spirometry. *Am J Ind Med*. 2001;39(5):443–53.
 21. Jaakkola MS, Suuronen K, Luukkonen R, Järvelä M, Tuomi T, Alanko K, et al. Respiratory symptoms and conditions related to occupational exposures in machine shops. *Scand J Work Environ Health*. 2009;35(1):64–73.
 22. Wlaschitz P, Höflinger W. A new measuring method to detect the emissions of metal working fluid mist. *J Hazard Mater*. 2007;144(3):736–71.
 23. National Institute for Occupational Safety and Health (NIOSH). Metalworking fluids (MWF) all categories (method: 5524, issue 1). In: NIOSH manual of analytical methods (NMAM). 4th ed. Atlanta, GA, USA: Centers for Disease Control and Prevention; 2003. Retrieved June 2, 2014, from: <http://www.cdc.gov/niosh/docs/2003-154/pdfs/5524.pdf>.
 24. Simpson AT, Stear M, Groves JA, Piney M, Bradley SD, Stagg S, et al. Occupational exposure to metalworking fluid mist and sump fluid contaminants. *Ann Occup Hyg*. 2000;47(1):17–30. Retrieved June 2, 2014, from: <http://annhyg.oxfordjournals.org/content/47/1/17.full.pdf>.

25. Reh BD, Harney JM, McCleery RE, Mueller CA. Evaluation of the NIOSH MWF total particulate matter: thoracic particulate matter conversion factor in a machining environment. *J Occup Environ Hyg.* 2005;2(4):239–43.
26. Fallah Vadeghani M. The survey of MWF air pollution in a metalworking shop and suggesting the controls [Master of Science in Public Health thesis]. Tehran, Iran: Islamic Azad University; 2005. In Persian.
27. Park D, Stewart PA, Coble JB. A comprehensive review of the literature on exposure to metalworking fluids. *J Occup Environ Hyg.* 2009;6(9):530–41. Retrieved June 2, 2014, from: <http://annhyg.oxfordjournals.org/content/53/3/271.full>.