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Study on Personal Exposures with Airborne Particulate Matter in Iron Casting Factories

Seyedtaghi Mirmohammadi

Faculty of Health, Mazandaran University of Medical Sciences, Mazandaran, Sari, Iran

Abstract: Commonly, all the particulate matters (PM) can effect on workers respiratory system. Airborne particle matters pose a greater health risk because it can deposit deep in the worker's lung and is harmful to health. The aim of this study was to determine the personal exposures to toxic PM in the workplace. Overall, one hundred participants were chosen for active personal sampling during working shift. SKC sampler equipped with membrane filter gathered indoor air by personal SKC pump for time weighted average. The atomic spectroscopy technique was used to determine toxic particle concentration. The average of toxic airborne particle (Mn) was 1.626mg/m^3 and the mean personal exposure to PM_{10} was 34mg/m^3. The mean measured psychrometric parameters were 29°C, 52%, 1.2m/s for dry temperature, relative humidity and air velocity, respectively. The correlations between personal exposures and indoor air parameters measurements showed a high significant relationship between personal exposure and dry temperature and wind speed in the factory ($P< 0.05$). This study revealed that there is a high exposure to toxic particles in the workplaces and also for particulate matters with $\leq$10 micron.

Key words: Particulate matters · Exposure · Dry temperature · Sampler · Workplace

INTRODUCTION

The melting process involves foundry, crushing and grinding of molding materials generates particulate matters (PM) and dust in the workplaces. The process is very high-temperature system and other shop inside the factories help to generate variety of dust in a hot workplaces. The polishing and finishing process, using sandblasting and drilling that are both environmentally pollutant for personals and factories. Particulate matters are relatively plentiful and variable component of the indoor atmosphere in the foundry factories. It is produced and emitted naturally to the atmosphere in the melting decomposition, combustion and finishing process [1, 2].

Ferrous foundry workers are exposed to PM in the workplaces from both naturally occurring processes and processing activities. In such factories sources of PM include furnaces, melting process, cars, lift trucks, sanding and combustion. Because of their small size, fine particles tend to remain and suspending in the air for long periods of time (weeks or months). Usually, the health effects of PM are likely to depend on several parameters, including the duration of and level of exposure, size of the particles and individual characterization of the exposed subject. PM may also cause asthma or may lead to premature death, mostly in someone who have preexisting cardiovascular and respiratory diseases [2]. Pollution resulting from carbon suspended particulate matter may place an excessive burden on the respiratory system and tend to increased morbidity and mortality, especially among at risk people in the factories and the general population [3, 4]. There are several factors such as other air pollutants, molds, allergens or ozone can cause respiratory symptoms correlated with personal exposure to PM. It is clearly that determination of whether PM or some other factor is responsible for an individual's symptom(s) is difficult [4]. Several academic documents have been reviewed related to $PM_{2.5}$ personal exposure [5, 6, 7] widely among the latest EPA Criteria document represent the most new and systematic survey. To one side from other literature, exposures to particles can exacerbate existing cardiovascular and respiratory diseases is a commonly agreement [4]. Though, there is a lake of epidemiological data with emphasis on role of gaseous pollutants continues to represent work related disease based on particulate exposure. The results of many studies have demonstrated that ambient particulate matter (PM)

Corresponding Author: Seyedtaghi Mirmohammadi, Faculty of Health, Mazandaran University of Medical Sciences, Mazandaran, Sari, Iran.

concentrations can cause respiratory and cardiovascular disease [3, 8]. Obviously, many workers spend their working time in the workplaces and they are exposed with ambient PM determine PM personal exposure and their sources in the work area and effect on workers health many surveys have been conducted by researchers. As a comparison between indoor and outdoor air pollution, some studies have illustrated that personal exposure to PM is high relationship with indoor air but poor relationship with outdoor air [9, 10]. Moreover, other studies have demonstrated that there are a regression relationship between personal exposure to PM in the workplaces and individual characterization and duration of exposure [10, 11, 12]. There is a need to find personal exposure with toxic and contaminated particulate matters in foundry factory based on effective parameters such as psychrometric condition and geographical variables; it may improve our understanding of what humans are actually exposed to and how to decrease this exposure [12]. The indoor air study assess factory pollutant problems can effect on human health with variety study models such as regression model or multiple model for pollution estimation with emphasis on particle matter in the workplaces. Similarly, the regression model used before by other researchers in terms of pollution predictive model [13-15]. There are many toxic materials as airborne particles in the melting process such as manganese, chromium, cadmium, magnesium etc., in the foundry workplaces. In such process activity few of them suspended in the breathing zone of workers and will inhale and remain their toxic effect on the human organs. The main toxic raw material for the related workplaces is manganese and it can harm on human brain and it has a chronic effect as a brain disease. Manganese is a necessary element, which is essential in small quantities but in higher doses might be a neurotoxic matter. High exposure to airborne manganese may lead to accumulation of the compound in the basal ganglia of the brain [16,17], where it may toxic condition [18]. Researchers reported that the neurological disorder of manganese (`manganism') that bears many similarities to Parkinson's disease [8,19]. While particulate matters levels (especially at size less than 10 microns) has been obviously illustrated to be related to health and environmental impacts [20, 21], therefore the need to monitor levels of suspended particulate matter in the foundry factories by a standard procedure and available technique to determine workers health situation in the workplaces. The objective of this research is to basically identify and determine concentration of the concentration of particulate matter (PM_{10}) emission arising from melting and molding process activities and manganese exposure, also compare concentrations of these pollutants with acceptable regulatory standards and make recommendation on how to improve their effects.

MATERIALS AND METHODS

One hundred workers (in furnace, melting, molding, blasting, drilling, finishing and transporting task) were chosen for the personal sampling during a working shift in the current study. Sampling and data collection and results documentation were done in accordance with the National Institute for Occupational Safety and Health guidelines and Standards.

Study Design: The study was conducted in Iran. Based on the study objectives, the indoor particulate matter (PM_{10}) concentration was measured during a working shift in the foundry factory. Besides, to gravimetric analyses, reflectance of all personal, indoor PM_{10} filters was measured. Sampling began in July 2012 and continued to September 2013. A lot of one hundred workers started the study to evaluate personal exposures to manganese and PM_{10}. The SKC personal samplers were fixed on subject's collar based on occupational health standard method for two times (first for manganese and second for PM). They use the samplers during the working shift at their workplace. A simple questionnaire was used to record the individual Information for participant workers. Questions were asked about age, weight, height, during of work, previous experience and smoking.

Sampling and Analytical Method: According to latest particulate matters sampling methods have been published, the IP-10A Method Update sampling and measurement method was chosen from EPA [22] and used for the current study. Personal PM_{10} was measured via the patented (U.S. Patent No. 7,334,453) SKC single-stage equipped with a 37-mm, 2-μm pore size membrane filter with support ring is used as the filtration medium and for Mn a sampler of Dewell Higgins type Respirable Cyclone (part number 225-69) and 25mm MCE 0.8 micron filters (part number 225-19, pk/50) was used with ester cellulosic filter (37mm, 0.8 pore size). Indoor samples were taken in the workplaces in the working time for time weighted average (TWA). It is supported by a stainless steel screen that is supplied with the personal environmental monitor. In the laboratory, the weighing room was set on 22°C and 40% as a permissible temperature and relative humidity, respectively. The SKC Leland Legacy pump was calibrated with a soap film flow meter in the laboratory at 2 liters per minute (± 5%) and distributed to the workers for personal sampling. After sampling all the PTFE filters were stored in a laboratory refrigerator at 41°C until they were analyzed (storage duration is 90 days). Samples were analyzed in a same time in the study laboratory. Filters were weighted using a Sartorius ME 5 (Sartorius AG, Gottingen, Germany) laboratory microbalance after equilibration in a weighting room where temperature and relative humidity were checked. Basically, the procedure of gravimetric technique is calculating of the sample mass average by taking the difference of the average post weight and average pre weight. Atomic absorption spectroscopy was carried out to determine manganese concentration of the collected samples. A Perkin-Elmer with Current lamp 20 Ma, gap 0.2 nm, 10 ml matrix modifier based on OSHA ID-121 and NIOSH 7301 methods.

Sample Size and Statistical Analysis: The sample size required to produce an estimate of the total number of samples and subjects (or of potentially exposed workers) within specified limits, with 95% confidence, was calculated using the formula:

$$n = \frac{NZ^2_{1-\frac{\alpha}{2}}\, p(1-p)}{d^2(N-1) + Z^2_{1-\frac{\alpha}{2}} P(1-p)}$$

Christensen, (1997) explained that multiple linear regression attempts to correlate the relationship between two or more variables and a response variable by fitting a linear equation to observed data [23] and other researchers used the regression techniques to correlate pollutants indicators as a function of psychrometric parameters and other factors relevant to factory [24], such as dry bulb temperature, relative humidity, dimension of factory and altitude of factory. The correlation between airborne fine particulate matters and psychrometric variables can be understood better by using multiple regression correlations. The general approach is to correlate PM_{10} concentration with independent variables, which include psychrometric data.

RESULTS

Lots of one hundred workers were chosen as exposed subjects. The study group included all production and supervisory workers assigned to the melting process line. The study group also included maintenance employees working in the workplaces. Workers were selected at random from within the corresponding frequency categories, because there were few old workers employees in the study group. The following items were abstracted from visits to the clinic face to face related to exposure: date of event, chemical substances involved, a description of exposure circumstances, the signs and symptoms reported by the employee and medical treatment rendered, referrals, physician diagnoses and any recommendations for temporary or permanent removal from the fine particulate matters work environment. Job specific work histories were coded for each person and linked to industrial hygiene measurements through social security numbers, job category and date. Peak exposure and (Time weighted average) TWA concentrations were aggregated on a job and time specific. Based on questionnaire responses the extracted factors associated with foundry factory and their contributions are elaborated in following tables:

Table 1 which is a statistical table includes the descriptive analysis of individual information which obtained from 100 workers in the factories.

The frequency of workers' information in the foundry factory; the mean age of workers was 33.12 years, the mean of history of work (work experience) was 6.7 years and the mean worker's weight was 74. Similarly, 18% of total workers working in the factory were smokers. As well 33% of total workers had some symptoms relevant to particle matters exposure.

The analysis of the data from Table 2 shows, PM_{10} concentration in the factory ranged from 13 mg/m³ to 89 mg/m³ and the average value for PM_{10} pollutant concentration was 34 mg/m³ and relative humidity ranged from 41 % to 56 % and the mean relative humidity was 52 % and dry bulb temperature ranged from 22°C to 27°C and the mean dry bulb temperature was 24°C. The indoor air velocity of the factory was between 0.9 to 1.5m/s.

Table 3 shows the average of PM_{10} and manganese concentration and other parameters in the factory. The mean PM_{10} concentration was 34 mg/m³ and this corresponds with mean relative humidity of 52%.

Table 1: Characteristics of subjects

Variables	N	Mean	SD	Min	Max
Age (year)	100	33.12	9.38	21	52
Weight (kg)	100	74.51	13.75	46	95
Work history (year)	100	6.7	7.649	8	21

Table 2: Mean of indoor air variables in the foundry factories

Variables		Results
PM10 , concentration (mg/m³)	Max	89
	Min	13
	Mean	34
Mn , concentration (mg/m³)	Max	1.626
	Min	0.25
	Mean	3.61
Relative Humidity, (%)	Max	56
	Min	41
	Mean	52
Dry bulb temperature, (C°)	Max	27
	Min	22
	Mean	24
Air velocity, (m/s)	Max	1.5
	Min	0.9
	Mean	1.2

Table 3: Regression correlation summary of fine particulate matters

Model	R	r²	Adjusted r²	SE of the Estimate
1	0.964	0.982	0.982	1.352

Predictors: (Constant), Relative humidity (%), Dry bulb temperature (°C), Air velocity (m/s)

Table 4: Coefficients of regression correlation for fine particulate matters and manganese pollution and indoor psychrometric parameters

	Coefficients		t	
Model	B	SE	7.707	P value.
(Constant)	11.355	3.274	3.469	0.001
Relative humidity (%)	1.35	0.06	22.564	0.0001
Dry bulb temperature (centigrade)	0.218	0.088	2.481	0.014
Air velocity (m/s)	1.121	0.07	18.243	0.92
Altitude (m)	0.89	0.051	-8.107	0.713

Dependent Variable: PM_{10} concentration (mg/m³)

Moreover, the result of Table 2 shows the mean PM_{10} concentration is corresponds with mean dry bulb temperature of 24°C in the factory.

Table 3 showed that 98.2% of the PM_{10} concentration can be attributed to any some or all of the independent variables (relative humidity, dry bulb temperature, air velocity and altitude) (r^2 = 0.982).

The correlation between RH and Td also air velocity and altitude and PM_{10} concentration were studied to understand the behavior of indoor air fine particulate matters with respect to indoor psychrometric parameters in the foundry factory. Linear regression analysis was used to assess the interactive behavior for PM_{10} pollution and indoor air psychrometric parameters. The extracted factors for foundry factory showed that all of the evaluated parameters correlated with PM_{10} concentrations are well defined in Table 4.

The multiple correlation coefficients (R) and the amount of variance (r^2,) are showed in Table 4. The following equation has been employed to stand for different parameters in order to measure the predictive regression correlation between psychrometric parameters and PM_{10} and manganese concentration of this study. According to coefficients extracted from Table 5, indoor air velocity (1.121) and altitude (0.89) were no significant in the final regression model, therefore it can be ignored to include in the model.

DISCUSSION

The maximum permissible exposure limit (PEL) of the PM_{10} concentration in the industries according to NIOSH standards for fine particulate matters in the factories should not exceed 15 mg/m³ (OSHA). Therefore, the concentration PM_{10} in the foundry factory detected (expressed in milligram per cubic meter) in the factories is 34, when compared to NIOSH standard appear to be extremely high. The result of this present study was slightly high compared to that of the other factories in different countries [17, 25]. While duration of work in the workplaces is important factor to determine of personal exposure to particles, it is supposed that health situation of subjects were different exposure condition compared to the general population and the exposure result s are similar to other research finding in the other country [26]. A high personal exposure was found for PM in the workplaces among subjects and it shown that there are high level of contamination of PM compared to OSHA permissible exposure limit, but the result of the current study is not comparable with other study was conducted by researchers [27]. The correlation between the average of indoor air variables and personal exposures to manganese and PM was not strong and a straight relationship has seen between PM pollution and condition of indoor psychrometric parameters. This finding if comparable with other results was obtained by other researchers [4].

As for the effects of relative humidity on particulate matters concentration, researchers observed that dispersion of PM during working process are inversely proportional to the relative humidity of the environment [28]. The electromagnetic properties of the particle-based components studied were found to be strongly influenced by the presence of water vapor during the curing process, as evidenced by the significant difference in the real relative permittivity of samples cured in different RH environments [18, 29].

The obtained regression predictive model in the current study is adapted with other finding that was achieved by researchers [17, 30]. They illustrated that determined pollution were compared to the predictions of the thermodynamic models GFEMN [30] in order to estimate the contribution of particulate matters to water absorption. A direct comparison with the obtained particulate matters model is possible for the GFEMN and AIM models [17] calculated the amount of aerosol bound water based on the measured relative humidity and the PM aerosol concentrations. Both models supposed that organic compounds do not contribute to water absorption. Thus any difference between the current regression model and the other model predictions showed the influence of particle matters and chemical matters on the absorption of water. This model supposed that the particle matters are dry during the low RH measurement and it is similar to other study results [31-33]. Moreover, there is no trustworthy information existing for the activities of particulate matters in water solution below 30% RH to accurately model the water content at such a low RH. In this study, the use of multiple regression models to examine exposure distributions that embraced the data on a wide range of indoor air has not been previously reported in the occupational hygiene literature.

CONCLUSION

The result of this study revealed that, the average concentration of fine particulate matters in the foundry factories is more than 34 mg/m^3 and 1.626 for manganese for time weighted average, this value is higher than that permissible exposure limits of OSHA, it implies that the factory was studied is polluted with PM_{10}. The obtained predictive regression model of PM for foundry factory based on psychrometric parameters in this study shows that the relative humidity and dry bulb temperature are the main factors influenced on PM_{10} concentration in the workplaces. The multiple linear regression correlation is good tool to predict of fine particulate pollution condition based on psychrometric factors situation in the foundry industries.

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