Academia Journal of Environmental Science 4(10): 195-200, October 2016
DOI: 10.15413/ajes.2016.0123
ISSN: 2315-778X

Research Paper

Workplace Respirable Dust Monitoring and Risk Factor Assessment in Foundry Process

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Accepted 28th October, 2016

ABSTRACT

A study was carried out among iron foundry workers to assess occupational exposure to ambient respiratory dust in their work environment and rates of risk factors in each process using Bayesian decision analysis (BDA) and AIHA (American Industrial Hygiene Association) exposure categorization guidelines. A total of 93 respirable dust samples were collected in various processes, including the molding, melting, shake-out, heat treatment, felting and finishing units of the foundries. The mean concentrations of respirable dust were 1.40±0.86 mg/m^3 in the molding process, 1.42±0.63 mg/m^3 in melting, 0.56±0.59 mg/m^3 in shake-outs, 1.63±0.85 mg/m^3 in heat treatment, 2.17±0.61 mg/m^3 in felting and 3.30±3.47 mg/m^3 in the finishing sections, respectively. The mean levels of respirable dust in the finishing process exceeded the ACGIH standard (TLV 3.0 mg/m^3). The results of BDA showed that the respirable dust exposures were in AIHA category 4 for shake-outs (96.7% probability), felting (98.1% probability) and finishing (100% probability), respectively. The exposures belonged to category 3 for molding (52.8% probability), melting (79.4% probability) and heat treatment (40.3% probability), respectively. Therefore, it is required to have immediate control and safety adaptation by personal protective equipment of proper respiratory musk, engineer control, chemical analysis of respirable dust, exposure surveillance in order to prevent from being exposed to respirable dust among the foundry workers.

Key words: Dust exposure, foundry, Bayesian model and risk factor.

INTRODUCTION

The principal occupational problem in iron foundry operations is the air pollution caused largely by various process including molding, melting, shake-out, heat treatment, felting and finishing. Molding is the operation necessary to prepare a mold for receiving the metal. It consists of sand around the pattern placed in support, or flask, removing the pattern, setting cores in place and creating the gating/feeding system to direct the metal into the mold cavity created by the pattern, either by cutting it into the mold by hand or including it on the pattern, which is most commonly used.

In traditional melting processes, metal is superheated in the furnace. Molten metal is transferred from the furnace to a ladle and held until it reaches the desired pouring temperature. The molten metal is poured into the mould and allowed to solidify. Once the metal has been poured, the mould is transported to a cooling area. The casting needs to cool, often overnight for ambient cooling before it can be removed from the mould. Castings may be removed manually or using vibratory tables that shake the refractory material away from the casting in the shake-out process. Thermal reclamation (heat treatment process) is widely used to the point where organic materials, including the binders, are driven off. This process can return the sand to an 'as new' state, allowing it to be used for core making. Thermal reclamation is more expensive than mechanical systems.

In the felting process the gating system is removed, often using band saws, abrasive cut-off wheels or electrical cut-off devices. A 'parting line flash' is typically formed on the casting and must be removed by grinding or with chipping hammers. In the finishing process, the casting may undergo additional grinding and polishing to achieve the desired surface quality. The pollutants generated in the foundry include respirable dust (Cheng et al., 2008), heavy metals (lead, nickel, cadmium, chromium, manganese, tin, barium, talc, aluminum and beryllium, etc), metal fumes, iron oxide and silica (Anderson et al., 2008). The workers are chronically exposed to these hazardous pollutants during their jobs. The foundry workers are also potentially exposed to a number of other aerosols and gases including methylene diphenyl diisocyanate, polycyclic aromatic hydrocarbons, benzene and sulfuric acid mist etc (Liss et al., 1998; Chen et al., 2011; Hansen et al., 1994). Therefore, the workers are at an increased risk from chronic exposure to pollutants generated in the foundry.

Exposure to pollutants led to significant declines in lung function among the steelworkers who worked in the continuous casting process in foundries (Nemery et al., 1985). Foundry workers also have a significantly increased risk for lung cancer, genotoxic damage and bronchitis (Liu et al., 2010; Yoon et al., 2014; Sobaszek et al., 1998; Kärävä et al., 1976; Johnson et al., 1985; Baur et al., 2012).

Exposures at iron foundries where scrap iron is recycled to produce cast iron can be substantially higher where effective safety and hygiene practices are not adopted. Smaller foundries typically are not equipped with dust precipitators and fume extractors, resulting in higher exposures for workers in such facilities.

This study was designed to assess occupational exposures to respirable dusts among workers at several cast iron foundries.

MATERIALS AND METHODS

Subjects

The study was conducted in the casting foundries located in Southern India. The monitoring was carried out after a preliminary walk-through survey in all the plants and shop floor where the molding, melting, shake-out, heat treatment, felting and finishing process were performed.

Sampling of respirable dust at different process units in the foundries was conducted with SKC personal sampling pumps Model 224-PCXR8 (SKC, Pittsburgh, USA) followed by NIOSH 0600 analysis. The pumps were previously charged and calibrated at the site. The personal sampling pumps were equipped with 37 mm aluminum cyclone filter heads, loaded with glass paper filters (0.8 μm pore size) and put on the workers during the shift. The respirable dust was sampled for 8 h. At the end of each shift, the pumps were removed and the filters analyzed by gravity metric method. A total of 93 respirable samples were collected in this study in the six process units. Dust concentrations were calculated for each of the sample and mean dust concentrations also estimated.

The concentration of respirable dust (mg/m^3) was assessed based on the formula:

$$C = \frac{(W_2 - W_1) \times 10^3}{T \times Q}$$

Where:

C= Dust concentration in the air in mg/m^3;
W_1= Filter's weight before sampling in milligrams;
W_2= Filter's weight after sampling in milligrams;
T = Time of sampling in minutes;
Q = Amount of sampling pump's flow in liters/minute (with correction of sampling air capacity over capacity in standard situation).

Prediction analysis using Bayesian model

In this study, a AIHA exposure categorization (Hewett et al., 2006) scheme and a Bayesian decision analysis (BDA) tool together were used to categorize exposures of workers in the foundry process. A frequent objective when collecting exposure data is to classify the exposure profile, or distribution of exposures into one of five exposure categories: 0, 1, 2, 3, or 4 corresponding to trivial (or very low) exposure, highly controlled, well controlled, controlled and poorly controlled exposures. Using the AIHA exposure categorization scheme, an acceptable exposure group is one where the true group 95th percentile exposure (for a reasonably homogeneous group) is less than the single shift exposure limit. Consequently, an unacceptable exposure group is one where the true 95th percentile exceeds the limit. IHDA-Student 2015 (IH Data Analyst-Student 2015, Exposure Assessment Solutions, Inc. www. OESH.com) was used for data analysis based on Bayesian statistics as a tool for decision making. The BDA tool uses the AIHA exposure categories (Table 1) and calculates the probability of the 95th percentile of the exposure distribution for each similarly exposed group (SEG) exceeding the exposure limit. The results are presented in the form of three decision charts (prior, likelihood and posterior). We assumed a uniform prior for all our calculations indicating that prior to making measurements, there is no evidence to assign higher probabilities to any of the five categories; the likelihood shows the probability of the 95th percentile being located in each of the five categories based solely on the measurements and the posterior reflects the synthesis of the prior and the likelihood. Since we have assumed a

Table 1: AIHA exposure categorization scheme (Hewett et al., 2006).

Exposure category[a]	Rule of thumb description[b]	Qualitative description	Recommended statistical interpretation[c]
0	Exposures are trivial to nonexistent— employees have little to no exposure, with little to no inhalation contact.	Exposures, if they occur, infrequently exceeds 1% of the OEL	X0.95 ≤ 0.01 × OEL
1	Exposures are highly controlled— employees have minimal exposure, with little to no inhalation contact.	Exposures infrequently exceeds 10% of the OEL	0.01 × OEL < X0.95 ≤ 0.1 × OEL
2	Exposures are well controlled— employees have frequent contact at low concentrations and rare contact at high concentrations.	Exposures infrequently exceeds 50% of the OEL and rarely exceed the OEL	0.1 × OEL < X0.95 ≤ 0.5 × OEL
3	Exposures are controlled—employees have frequent contact at low concentrations and infrequent contact at high concentrations.	Exposures infrequently exceeds the OEL	0.5 × OEL < X0.95 ≤ OEL
4	Exposures are poorly controlled— employees often have contact at high or very high concentrations	Exposures frequently exceeds the OEL	X0.95 > OEL

[a]An exposure category can be assigned to a SEG whenever the true 95th percentile exposure ($X_{0.95}$) falls within the specified range; [b]The "Rule-of-thumb" descriptions were based on similar descriptions as published by the AIHA; and [c]$X_{0.95}$ = the true group 95th percentile exposure.

Table 2: Exposure level and risk factors of workers in foundry process.

Section	N	Range	Median	Mean ± SD	GM ± GSD
		Concentration (mg/m³)			
Molding	25	0.5-4.03	1.21	1.40±0.86	1.22±1.64
Melting	25	0.61-3.11	1.20	1.42±0.63	1.3±1.51
Shakeouts	16	0.18-3.10	1.60	1.63±0.85	1.32±2.19
Heat treatment	4	0.1-1.35	0.43	0.56±0.59	0.34±3.58
Felting	10	0.81-3.01	2.36	2.17±0.61	2.06±1.45
Finishing	13	0.73-10.9	2.35	3.30±3.47	2.23±2.41

uniform prior, the likelihood and the posterior probabilities are identical.

RESULTS AND DISCUSSION

Table 2 shows the summary statistics for the respirable dust exposure data for each process unit of the foundries. Concentrations (mean ± SD) of respirable dust in the molding process were 1.40±0.86 mg/m³; in the melting process (1.42±0.63 mg/m³); shake-outs (1.63±0.85 mg/m³); heat treatment (0.56±0.59 mg/m³); felting (2.17±0.61 mg/m³) and in finishing (3.30±3.47 mg/m³) respectively. The levels were found to be relatively higher in the finishing section than the other process units and also the mean level exceeded the ACGIH standard (TLV 3.0 mg/m³) of respirable dust. The highest dust concentration was also observed in the finishing section and it was 10.9 mg/m³. The geometric mean concentration of respirable dust in the finishing process was 2.23 mg/m³.

Figure 1A to C shows the results of BDA (the three decision charts) for respirable dust for the molding process considering the exposure limit of 3 mg/m³ as per ACGIH. A uniform prior probability distribution was used to represent the situation where there was no prior knowledge or expectations regarding this particular process (Figure 1A).

Figure 1B shows the probability of likelihood decision for the molding process using monitoring data. Figure 1C presents the posterior as final decision probability of Figure 1A and B.

Figure 2A to F shows the results of the posterior decision probabilities using the Bayesian model based on the results (Table 2) of respirable dust identified in different process units of the foundry. Some of the processes were unambiguously category 4 exposures, for example, shake-outs (96.7% probability), felting (98.1% probability) and finishing (100% probability), respectively. This is consistent with Table 2 which shows higher median exposures for these three exposure groups.

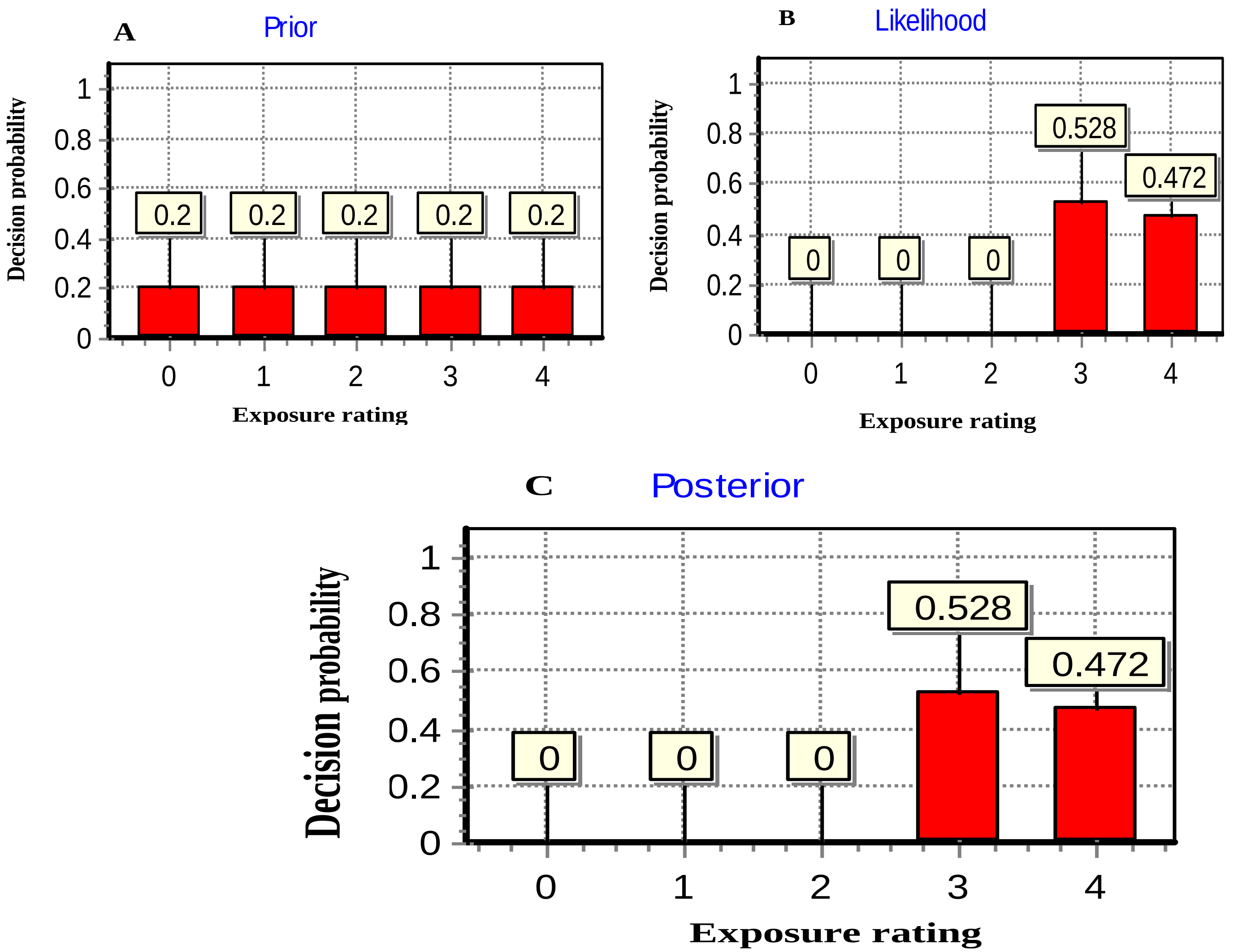

Figure 1: Bayesian modeling and assessment result of respirable dust concentration at molding unit process in foundry process.

From Figure 2A and B, it was observed that the percentage of highest exposure rating in molding (52.8%), melting (79.4%) and heat treatment (40.3%) respectively fall into the exposure category of 3 as per AIHA exposure categories (Table 1).

Conclusion

Table 3 contains a list of typical actions and controls as prescribed by AIHA for workplace exposure. By assigning the exposure profile we are able to suggest control measurement in each process to reduce the exposure of respirable dust.

In this study, we obtained from the result of prediction about each process unit by Bayesian model that the percentages of excess rate of respirable dust in the shake-outs, felting and finishing belongs to the highest grade (grade 4/4+) and molding, melting and heat treatment process were under grade 3. These two outcome final ratings indicated that the workers were frequently inhaling respirable dust. In the molding, melting and heat treatment process units workers have frequent contact at low concentrations and infrequent contact at high concentrations. In the shake-outs, felting and finishing units workers often have contact at high or very high concentrations. Hence, it is required to take fast actions on the control and safety measurement. Based on the action taken we can suggest the following guidelines (Table 3).

Therefore, it is essential to have immediate safety adaptation by personal protective equipment of proper respiratory musk or engineer control like local ventilations or cross ventilation in order to prevent being exposed to respirable dust to safeguard the workers health. There should also be the need of chemical analysis of respirable dust and exposure surveillance like (i) protection of health of the individual employee, (ii) detection at an early stage of any adverse health effects due to exposure of chemicals

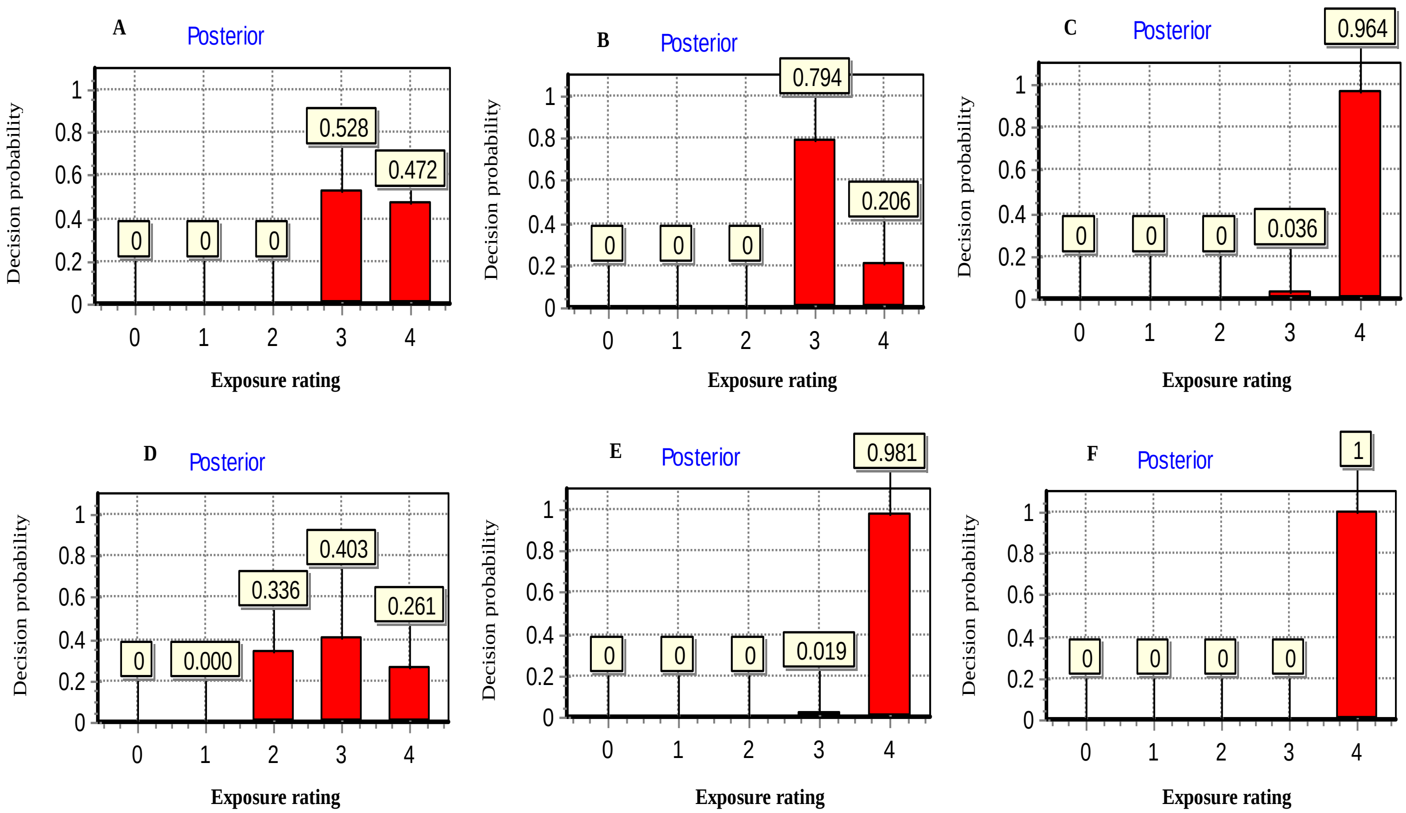

Figure 2(A-F): Bayesian modeling and assessment result of respirable dust concentration at different process units in foundry process. (A) Molding process; (B) Melting process; (C) Shake-outs process; (D) Heat treatment process; (E), Felting process and (F) Finishing process.

Table 3: Typical actions or controls that result for each final rating **(**Hewett et al., 2006).

Final rating	Action or control
0	No action
1	General or chemical specific hazard
2	Chemical specific hazard communication
3	Chemical specific hazard communication, Exposure surveillance, Medical surveillance, Work practice evaluation
4	Chemical specific hazard communication, Exposure surveillance, Medical surveillance, Work practice evaluation, Respiratory protection and Engineering controls
4+	+Immediate engineering controls or process shutdown ,Validate that respiratory protection is appropriate

enriched with respirable dust; (iii) assisting in the evaluation of control measures; (iv) detection of hazards and assessment of risk or (v) the disease or health effect associated with exposure.

ACKNOWLEDGEMENT

The authors are highly grateful to The Director, National Institute of Occupational Health for granting permission to conduct the study. The authors also acknowledge the ROHC(S)'s staffs for conducting the study. We appreciate the management and workers of foundries for their full co-operation in conducting this study.

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Cite this article as:

Sen S, Jogattappa N, Ramachandran G, Ravichandran B (2016). Workplace Respirable Dust Monitoring and Risk Factor Assessment in Foundry Process. Acad. J. Environ. Sci. 4(10): 195-200.

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