Workplace Respirable Dust Monitoring And Risk Factor Assessment In Foundry Process

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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 by 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, shakeout, 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 shakeouts, 1.63 ± 0.85mg/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 exceed the ACGIH standard (TLV 3 mg/m^3). The results of BDA show that the respirable dust exposures were in AIHA Category 4 for shakeouts (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.*
Keywords: *dust exposure, foundry, Bayesian model and risk factor*

I. Introduction

The principal occupational problem in iron foundry operations is the air pollution caused largely by various process including molding, melting, shakeout, 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 by 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 shakeout 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 bandsaws, 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 [1], heavy metals (lead, nickel, cadmium, chromium, manganese, tin, barium, talc, aluminum, beryllium, etc), metal fumes, iron oxide, and silica [2]. 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 di-isocyanate, polycyclic aromatic hydrocarbons, benzene, sulfuric acid mist etc. [3-5]. Therefore, the workers are at an increased risk from chronic exposure to pollutants generated in the foundry.

Exposure to pollutants have caused significant declines in lung function among the steelworkers who worked in the continuous casting process in foundries [6]. Foundry workers also have a significantly increased risk for lung cancer, genotoxic damage and bronchitis [7-12]. 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.

II.   Materials And Methods

II.I 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, shakeout, 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 had previously been charged and calibrated at the site. The personal sampling pumps were equipped with 37 mm aluminum cyclone filter heads, were loaded with glass paper filters (0.8 μm pore size) and were put on the workers during the shift. The respirable dust was sampled for 8 hours. At the end of each shift, the pumps were removed and the filters were analysed by gravity metric method. A total 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 were also estimated.

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

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

C   :   Dust concentration in the air in mg/m3
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)

III.II Prediction analysis using Bayesian model-

In this study a AIHA exposure categorization [13] 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, were 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 shown in 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 have 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 uniform prior, the likelihood and the posterior probabilities are identical.

Table 1 : Aiha Exposure Categorization Scheme [13]

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 exceed 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 exceed 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 exceed 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	Exposures infrequently exceed the OEL	0.5 × OEL < X0.95 ≤ OEL

	infrequent contact at high concentrations.		
4	Exposures are *poorly controlled*— employees often have contact at high or very high concentrations	Exposures frequently exceed 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 published by the AIHA.(2)*

[C]*$X_{0.95}$ = the true group 95th percentile exposure.*

III.   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/m^3; in the melting process were 1.42±0.63 mg/m^3; in shakeouts 1.63±0.85 mg/m^3; in heat treatment 0.56±0.59 mg/m^3; in felting 2.17±0.61 mg/m^{3}and in finishing 3.30±3.47 mg/m^3 respectively. The levels were found to be relatively higher in the finishing section than the other process units and also the mean level exceed the ACGIH standard (TLV 3 mg/m^3) of respirable dust. The highest dust concentration also observed in the finishing section and it was 10.9 mg/m^3. The geometric mean concentration of respirable dust in the finishing process was 2.23 mg/m^3.

Table 2: Exposure Level And Risk Factors Of Workers In Foundry Process

Section	N	Range	Median	Mean±SD	GM±GSD
		Conc.(mg/m$^{3)}$			
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

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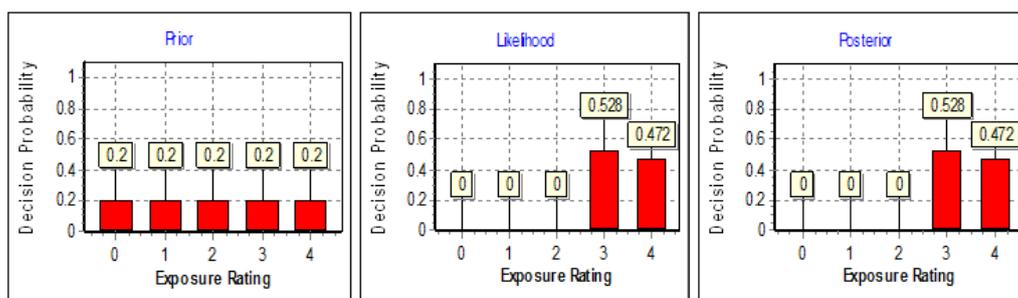

| Fig 1A | Fig 1B | Fig 1C |

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

Figure 1B shows the probability of likelihood decision for the molding process using monitoring data. Fig.1C presents the posterior as final decision probability as the of Figure 1A and Figure 1B. Figures 2A- 2F show 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, e.g., Shakeouts (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. From Figs.2 (A) and 2(B) it was observed that the percentage of highest exposure rating in molding 52.8%, melting 79.4% and heat treatment 40.3% respectively and fall into the exposure category of 3 as per AIHA exposure categories (Table –I) .
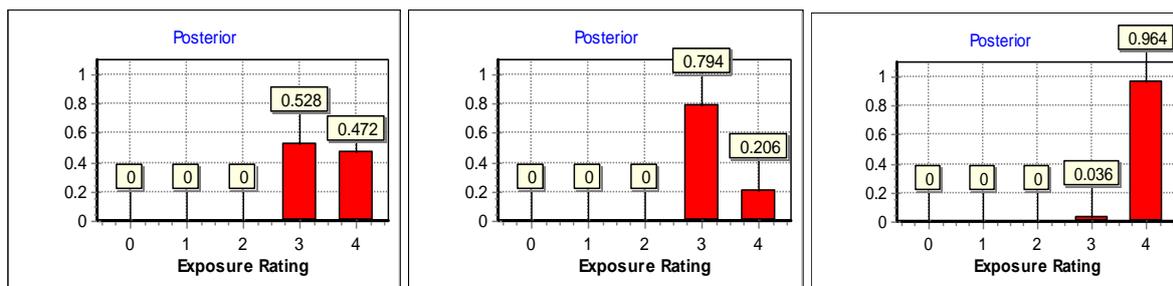
Fig 2(A), molding process **Fig2**(B), melting process **Fig2**(C),Shakeouts process
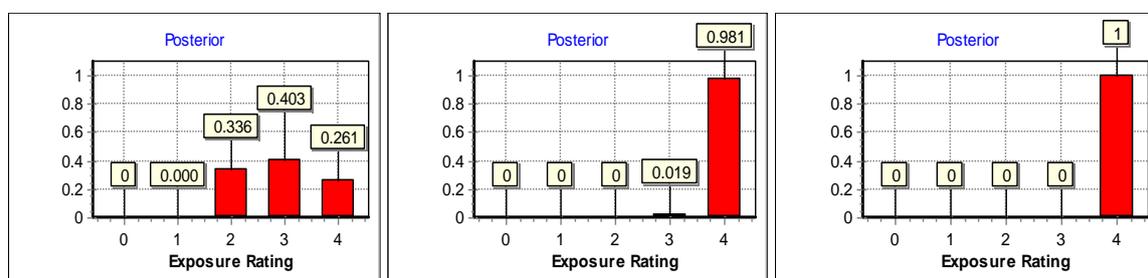
Fig 2(D), Heat Treatment process **Fig2**(E), Felting process **Fig2**(F), finishing process
Figure 2: Bayesian modeling and assessment result of respirable dust concentration at different process units in foundry process

Table 3 contains a listing 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.

Table 3: Typical Actions Or Controls That Result For Each Final Rating [13]

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

IV.   Conclusion

In this study, we have obtained from the result of prediction about each process unit by Bayesian model that the percentages of excess rate of respirable dust in the Shakeouts, Felting and Finishing were belongs to the highest grade (grade 4/4+) and molding, melting and heat treatment process were under grade 3. These two outcome final ratings indicating that the workers were frequently inhaling respirable dust. In the molding, melting and heat treatment process unit's workers have frequent contact at low concentrations and infrequent contact at high concentrations. In the Shakeouts, Felting and Finishing unit's workers often have contact at high or very high concentrations. So, it is required to take the fast actions on control and safety measurement. As a action taken we can suggest the follow the guideline as per 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 from being exposure to respirable dust to safeguard the worker's health. There should also 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 any adverse health effects due to exposure of chemical enrich of 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.

Acknowledgment

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