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Estimation of heavy metal exposure in workplace and health risk exposure assessment in steel industries in Iran

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ABSTRACT

Measuring air pollutants such as heavy metals in the workplace, usually takes a long time, equipment and budget and due to variation in concentration, the results of short term researches are not reliable. To assess the health risk of workers in the smelting unit of an alloy steel factory to long term exposure to heavy metals, a simple, fast and less expensive method was used for evaluation with the combination of suspended dust analysis and PM_{10} measuring. The results showed that the highest and lowest concentration value was respectively recorded for Pb and Cd. Although, the average concentrations of heavy metals were lower than the recommended levels of occupational exposure, their occupational carcinogenic risks were different. The carcinogenic risk of Pb, Ni and Cd was low and acceptable, but was higher and unacceptable for Cr; therefore, using protective respiratory equipment and more efficient local ventilation was recommended.

1. Introduction

Exposure assessment of heavy metals implies identifying and quantifying their sources, how they enter the human body and their adverse effects on human health [1]. The health risk is especially high for workers involved in smelting because of emissions of harmful pollutants such as heavy metals in the workplace. Hence, metal smelting is regarded as one of the most important anthropogenic heavy metal emission sources [2,3]. During the smelting process, heavy metals are evaporated from the metal matrix due low boiling point and high temperature [4].

In order to evaluate the health risk, further researches on dust exposure parameters are necessary to reduce the uncertainties associated in risk calculations [5]. Air pollution and cancer risk assessments were evaluated to determine the level of air pollution from particular metals in selected localities and the cancer potential as adverse effects on humans by observing metals over a period of time [6]. Suspended dust particles present in polluted air are known to cause adverse health effects in humans as they may be absorbed into the lung tissues while breathing. Moreover, harmful elements such as heavy metals in different forms, when inhaled or ingested, can cause serious health hazards to humans [7]. It is important to study air quality in areas around industries since significant releases of metals to the environment could represent a threat to local communities [8]. Risk calculations for exposure to heavy metals in Guangzhou, China with a simple exposure assessment model showed that the cancer risks of the bioavailable fractions of arsenic, chromium and cadmium were 3–33 times greater than the permissible levels, indicating serious health risks to the residents of this urban area [9].

Air pollutants in the workplace can gradually have undesirable effects on the health of workers. Industrial empowerment worsens the problem [10]. The concentration of some pollutants indoors can be greater than their concentration outdoors [11].

One of the major and important industries in pollutant emissions is the steel industry. Occupational health problems among workers in the steel industry have attracted the attention of investigators. In addition, the workers are sources of epidemiological studies for resident populations around steel industries.

Workplace stress in iron and steel industry are numerous and typically include: inhalable agents (gases, vapors, dusts and fumes), working in confined spaces, lack of adequate ventilation, less occupational safety and health training and poor supervision over the use of personal protective equipment among others [12]. In the iron and steel industry, during the melting and casting operation, harmful pollutants such as gases, vapors, fumes, and smoke may be produced. The major pollutants are emitted during processes such as molding, mould drying, furnace preheating, Elec-

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tric Arc Furnace (EAF) and discharge among others [13–15]. Metals such as cadmium, lead, zinc, mercury, manganese, nickel and chromium can be emitted from a furnace as dust, fume or vapor or may be absorbed by particulates [16].

Particulate matter (PM) due to its physicochemical properties is one of the most important pollutants in the air that has undesirable effects on human health. In particular, particle composition and hazardous chemical contents can cause damage to the health of an exposed person [17]. More recent studies have confirmed the role of heavy metals' toxicity in PM [6,18,19]. The deleterious effects of heavy metals on human health have been demonstrated in many ways. Exposure to these pollutants causes acute and chronic toxicity and many diseases such as neurological disorders, food deficiency, hormone imbalance, obesity, abortion, cardiopulmonary disease, liver and kidney damage, allergies and asthma, chronic viral infections, reduction of body's tolerance, infertility, anemia and fatigue, weakened immune system, genetic damage, premature aging, memory loss, osteoporosis, hair loss, insomnia and different kinds of cancer [2,20] and mental hypogenesis in children and death [21].

As Abdel-Rasoul et al. (2009) point out, frequently recorded health disorders among iron and steel industry workers include: respiratory (66%), skin problems (31%) and noise-related hearing impairment [22]. Dinis and Fiuza (2011) [1] posited that long-term exposure can cause slower progressive physical, muscular, and neurological degenerative processes. Allergies may also occur and repeated long term contact with some metals or their compounds may become carcinogenic. Liu et al. (2013) [23] reported the effect of outdoor air pollution in the vicinity of a steel plant on cardiovascular physiology in Sault Ste. Marie, Canada.

There is evidence that exposure to irritating dust and fumes may also make steelworkers more susceptible to a reversible narrowing of the airways (asthma) which over time may become permanent [24,25]. Shrivastava (2009) [13] reported mortality from lung cancer in steel industry workers due to exposure to chromium and PAHs (Polycyclic Aromatic Hydrocarbons).

In some studies, exposure data during melting in stainless steel manufacture was recorded as mean dust concentration of 2.3 ± 1.3 and 1.8 mg/m^3. Also, Cr concentration in chemical dust composition was reported as 30 $\mu g/m^3$ [26].

Aiming to evaluate exposure risk of workers to heavy metals such as lead (Pb), chromium (Cr), nickel (Ni) and cadmium (Cd) emitted from iron and steel processes, this study was conducted to assess the smelting unit of Iran Alloy Steel Industries (IASI) in 2012–13. This metallurgical industrial complex is located 25 km northwest of Yazd city, Iran. The smelting unit of IASI has 3 electric-arc type furnaces with an annual mean production of 352,000 tons of different kinds of steel. The factory utilizes first class iron slab along with ferrous metal scrap mainly from old automobile waste parts as its primary material in percentages based on availability and desired productions.

The present study focused on the estimation of heavy metal exposure in workplace and health exposure risk assessment among workers of alloy steel factory of Iran. A simple and fast method have been applied in combination of suspended dust analysis and PM_{10} measuring-PM10 is particulate matter 10 μm or less in diameter. PM_{10} concentration has been measured in two separate seasons (winter and summer). Three samples of dust from various locations in saloon that have the highest dust concentration among all the section that there is not air current were selected and analysed. For obtaining average dust breathing, TSI device was used and various samples during one shift in different location were used and for assessment of health exposure risk we applied combination of formulas.

2. Material and methods

2.1. Method of estimation

It is obvious that the particulate containing heavy metals is probably available in the workplace area. The ground surface particulate matter (PM) is usually cleaned or resuspended due to different activities in the workplace, but there are some micro-surfaces in far-to-reach areas inside the workplace which contain some suspended dust even for years. Passive sampling from these points and analyzing them for heavy metals content could give a more realistic conditions of dust composition (special pollutants) which the workers are exposed to during working hours. However, there is some uncertainty in the method especially unknown age of accumulated dust. It is obvious that the result of analyzing these types of dust composition can give more accurate composition of dust inhaled by workers over long working years than sampling over short periods for assessing their exposure. PM levels, which could penetrate the lungs can be measured by a size selective aerosol monitor and then multiplied by the average mean of PM_{10} mass at breathing height in the workplace and by composition percentage of any kind of dust content such as heavy metals to result in the concentration of that pollutant in the air of the workplace. It is shown in Eq. (1).

$$CA_{long\ term} = PM_{10mass} X\ \%A_{dust} \quad (1)$$

where $CA_{long\ term}$: is concentration of pollutant A for long term exposure in $\mu g/m^3$; $PM_{10\ mass}$: is average mean concentration of PM_{10} in the breathing zone workplace air; $\%A_{\ Dust}$: is the mass percentage of pollutant A in suspended dust.

2.2. Sampling and analyses

The smelting unit in the IASI includes 3 main EAF with an average of 130 workers, which work in 3 separate shifts in a big unified saloon. Although a local ventilation system evacuates the huge amount of polluted emission from the furnaces, usually the air inside the saloon is dusty and impure. Based on the presence of workers in their work stations, 21 points were selected as fixed stations for measuring PM_{10}. PM_{10} concentration was measured at selected stations at about 170 cm height breathing zone, with 5 min measuring time for each station. The measuring program was carried out 4 times within 2 h interval during daily work shifts and was repeated for two separate seasons (winter and summer) using a DustTruk Aerosol Monitor, TSI-8520.

In order to analyse heavy metals including Pb, Cr, Ni and Cd, three samples of suspended dust from 21 locations in the workplace and near the fixed stations were collected in glass dishes. The other samples were collected from different locations. This diversity in site selection for the dust sample collection caused the result to be near the real pollution rate that exists in the workplace during the study period. Dust samples were thoroughly mixed and then extracted with nitric acid using ISO9588 analysis method. To minimize errors and eliminate the effect of interference of probable contamination in the extraction process, two control samples were used during extraction according to the U.S. National Institute for Occupational Safety and Health guideline (NIOSH) [27]. The heavy metals content of extracted solutions was analysed using the Atomic Absorption Spectrophotometer Varian Spectra Model 100/200 by acetylene-air flame.

To initially assess the health risk of exposure to heavy metals, the Average Daily Intake (ADI) of each heavy metal via direct inhalation was determined using Eq. (2) [1], as follows:

$$ADI = (CA \times IR \times ET \times EF \times ED \times 0.001)/(BW \times AT \times 365) \quad (2)$$