

Indoor Air Quality in Steel Making Industries

Kamel K. Al-Zboon (Corresponding author)

Department of Environmental Engineering, Al-Balqa Applied University, Irbid, Jordan

Tel: 962-777-426-557 E-mail: Kalzboon@yahoo.com

Osric Tening Forton

Safeguards and Compliance Department (SNSC)

African Development Bank Group. Avenue Joseph Anoma

01 BP 1387 Abidjan 01, Côte d'Ivoire

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Abstract

Steel making industry is one of the major contributors to the global environmental catastrophes including climate change, photochemical smog and depletion of the ozone layer. Emissions from steel making process result in health impacts on workers and the neighboring communities. This study aimed to investigate indoor air quality in a steel making industry in Saudi Arabia. Indicative pollutants, SO₂, NO_x, CO, CO₂, O₃, PM₁₀ and PM_{2.5} were measured at eight locations across the factory. The obtained results indicated that loading, melting, slag pouring and casting stages are the major sources of indoor air pollution. In comparison with the ambient air, indoor concentrations increased up to: 13.50, 9.8, 1.29, 2.7, 15.6, times for SO₂, NO_x, CO₂, VOCs, O₃, respectively. Periodical medical check, pollution control, using of uncontaminated scrap, compliance with H&S regulations, are the key factors in reducing indoor emissions and subsequently improve occupational health.

Keywords: Air Pollution, Indoor Air Quality, Steel Industry, Occupational Health, Workplace

1. Introduction

Air pollution (indoor or outdoor) has negative effects on human health and environmental receptors (Salama and Berekaa, 2016). A significant correlation between long-term exposure (years) or short term exposure (several days) to air pollutants and adverse health effects has been reported. Health effects include: respiratory, neurological, cardiovascular diseases, irritation, cancer and cardiopulmonary mortality (Awad et al., 2016, Alharbi et al., 2014,

Chaurasia and Tiwari, 2016, Al-zboon, 2017). Globally, an estimated 7 million people die because of exposure to high level of indoor and ambient air pollution including particulate matter (PM_{2.5}, PM₁₀) and gaseous air pollutants (O₃, CO, NO₂, SO₂ and H₂S) (Jiang et al., 2016). Poor indoor air quality has been associated with building related illnesses such as headaches, fatigue, eye, and skin irritations (El-Sharkawy et al., 2014). In the industrial sector, indoor air pollution is considered one of the main causes of work-related diseases, and it is the major concern of the employers as well as the employees. In addition to its effect on human health and the environment, poor air quality affects the employees' comfortability and their productivity. As such, air pollution control is very important not only for the personnel health, but to achieve high employee productivity which will be reflected on the running costs and profits.

Concerted efforts have been made in developed countries to develop systems and processes, including standards against which evidence of indoor or outdoor pollution can be monitored and mitigation measures implemented for a wide range of industrial sectors.

Steel is one of the most widely used materials with annual production of 1.6 billion metric tons and the most recycled material in the world, making significant contributions to the gross domestic products (GDP) of the producing countries (UKSTEEL, 2018). More than 73% of the global steel production is produced by using oxygen blown converter (OBC) method, 25.7% by electrical arc furnace (EAF), and less than 1% by other methods (WSA, 2017). Steel making is a highly energy intensive process and every stage of the process has potential sources of the air pollutants which may have high effects on the employees' health.

Steel making is associated with the emissions of air pollutants into the ambient environment including PM₁₀, SO₂, NO₂, O₃ and CO₂ resulting in increased the risk of cardiovascular mortality, effect on pulmonary and cardiovascular function (Jena et al., 2011, EPRI, 2000, Shutt et al., 2017). Valenti et al. (2016), reported that 28 % of the sample population living around the steel plants in Brazil suffer from respiratory pathologies (Valenti et al., 2016). Lung function survey of steel factory workers showed a linear correlation between lung function indices and the accumulative respirable metal dust (Co, Cr, Ni) (Hamzah et al., 2016).

Indoor air quality is one of the environmental components most affected by emissions from steel production. Steel industry hazards includes: mineral dusts, metal fumes, combustion gases, resin bonding systems, physical noise, heat and vibration. It has been reported that the steel industry is responsible for many occupational diseases such as: headache, eyes and noise irritation, irritability of respiratory system, bronchitis, asthma, cardiovascular, fatigue and dehydration (Khullar and Gupta, 2017). The steel industry had evolved significantly over the decades with progressive technical developments improving the production process, including process changes from heavily to less polluting processes (Jena et al., 2011). These changes coupled with improvements in environmental regulations have resulted in improved air quality in the steel plants.

While there are much ongoing researches regarding the impact of the steel industries on the ambient air quality, there has been limited research relating to indoor air quality and workers'

health.

In order to develop and implement efficient mitigation measures, taking all necessary precautions to protect the health and safety of staff and others working within steel industries, it is important to understand the levels of common pollutants within steel factories in order to make informed decisions about environmental improvement.

In this paper we assess indoor air pollution from an electrical arc furnace steel smelting plant in Saudi Arabia. The results obtained from the study were interpreted in relation to potential human health risks and present a series of recommendations for improvements based on lessons learned from other parts of the world or other sectors.

2. Methodology

A steel making plant located in Riyadh, the capital of KSA was selected to investigate indoor air quality and possible effect on workers' health. This plant uses an electric arc furnace (EAF) with alkaline lining for steel pellets production. The raw material for steel making is mainly the scrap steel in addition to direct reduced iron, iron carbide, and pig iron. The production process includes: materials charging, melting, refining, slagging, tapping, secondary metallurgy, continuous casting, and cooling. The final products are pellets which are subjected to further production operations based on their final use.

Within the plant, samples were collected in the main sites where high emissions have typically been expected. The selected samples locations were from: the scrap area (N.1), loading area (N.2), melting area (N.3), casting area (N.4), slag pouring area (N.5) and the final products area (N.6). As a control, one sample (N.7) collected from the ambient environment outside the plant as a reference.

Data was collected using advanceSenso prob. made by Greywolf. The instrument is capable of measuring the emissions of CO, CO₂, SO₂, H₂S, NO₂, NH₃, O₃, VOC_s, humidity and temperature. Measurement can be taken for short time (walkover) or for long time (weeks). In this study, indoor air pollutants were measured every one min utilizing grab sampling technique during three successive operational days. The instrument was installed on a triangular stand at a height of approximately 1.5 m, with more than 2m away from the nearest obstacles to avoid any potential interference during sampling (Muhamad-Darus et al., 2011). Particulate matters (PM₁₀, PM_{2.5}, and TSP) were measured using dust profiler from Aeroqual. All instruments were calibrated before used.

3. Results and Discussions

3.1 Concentration of SO₂

Sulfur dioxide is a very important air pollutant has taken significant concern by researchers due to its high impact on the environment especially in the formation of acid rain phenomenon. About half of the produced sulfur dioxide in the steel industry is caused by oxidation of sulfur during sintering and pelleting process.

The concentration of SO₂ ranged from 0.02 at the cooling area to 0.27ppm at the furnace area

(melting) as shown in Figure 1. Also, the loading and the casting areas have high concentration (0.22 and 0.18ppm respectively) indicating high increase in comparison with the ambient level of 0.02ppm. The potential sources of sulfur in EAF process include: charging of raw materials (mainly scraps), others auxiliary materials, and the first fusion pig iron (Iluțiu – Varvara et al., 2013).

Regarding its effect on workers' health, a concentration of 5 ppm may increase the resistance of airways, 10ppm cause high irritation of throat, nose, and eyes, and may cause paralysis and death at higher concentration (>20ppm) with long exposure period (Iluțiu – Varvara et al., 2013). Australian government limited SO₂ in the workplace at 2ppm for 8-Hour Time-Weighted Average (TWA) and 5ppm for an exposure period of 15min (Short term exposure limit, STEL) (SWU, 2018). The measured values are far below the reported harmful level, so no health effect might be expected.

It worth mentioning here that there is no confined space in the process lines and all production areas are connected spatially provides high dilution of pollutant between all areas, inside and outside the plant which may resulted in a reduction of concentration in some areas and increase it in other areas.

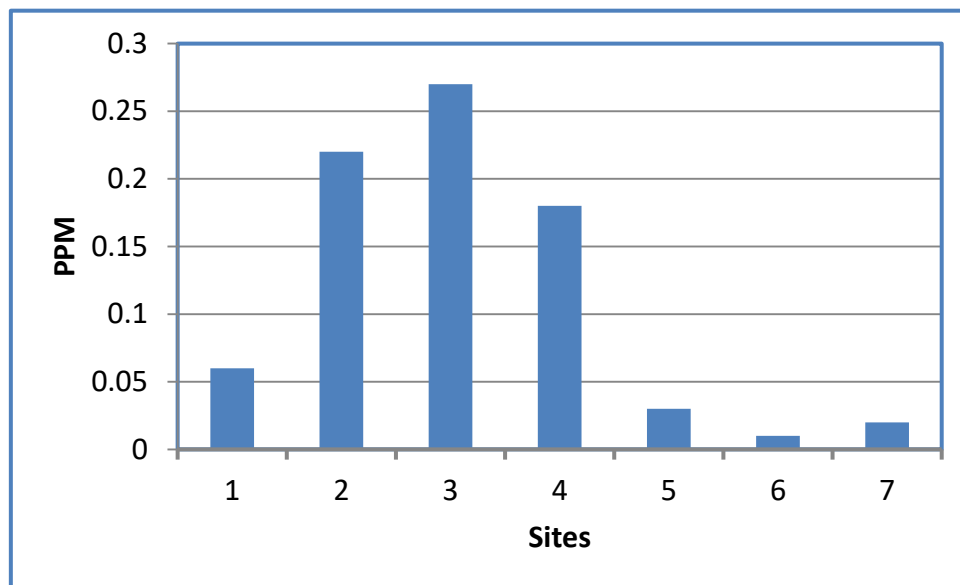


Figure 1. SO₂ concentration

3.2 Concentration of NO₂

At high temperature, combustion process generates NO_x emissions which have significant impact on the environment including its contribution to smog and acid rain formation (Chan et al., 2004).

It has been reported that in addition of CO₂, NO_x is the second most detected pollutant gas in EAF with production rate of 0.12- 0.32 kg/t (Echterhof and Pfeifer, 2011). It is generated due

to the oxidation of N₂ in the atmosphere at high temperature and due to oxidation of nitrogen compounds in used fuel or due to the reaction of nitrogen radical with hydrocarbons. However due to the high temperature in the EAF, thermal mechanism is the predominant for of creating NO_x(Chan et al., 2004, Kirschen et al., 2005). NO_x health effect is the focus of all health and safety agencies worldwide; for example department of Employment, Economic Development and Innovation in Queensland government (DEEDI) pointed out that the average level of exposure should be <3ppm during the working day, while a level of 20ppm has immediate dangers to life and health. Health effects include: irritation of airways, eye, throat, and lungs, trigger asthma and pulmonary edema (DEEDI, 2018).

In our survey, the concentration of NO₂ ranged from 0.07 at the scrap yard to 0.49ppm at the furnace area in comparison with 0.05 at the ambient air (Figure 2). Also significant levels were detected in the loading, casting and slag pouring areas, while lower level was in the cooling area. At the furnace area, NO₂ is generated via two processes, start-up of the melting process, and through post combustion of carbon oxides and hydrogen inside and outside the furnace (Kirschen et al., 2005). SWU limited NO₂ concentration at 3 and 5 for TWA and STEL respectively. Lower level of measured NO₂ in comparison with SWU guidelines indicated that no health effects were expected (SWU, 2018).

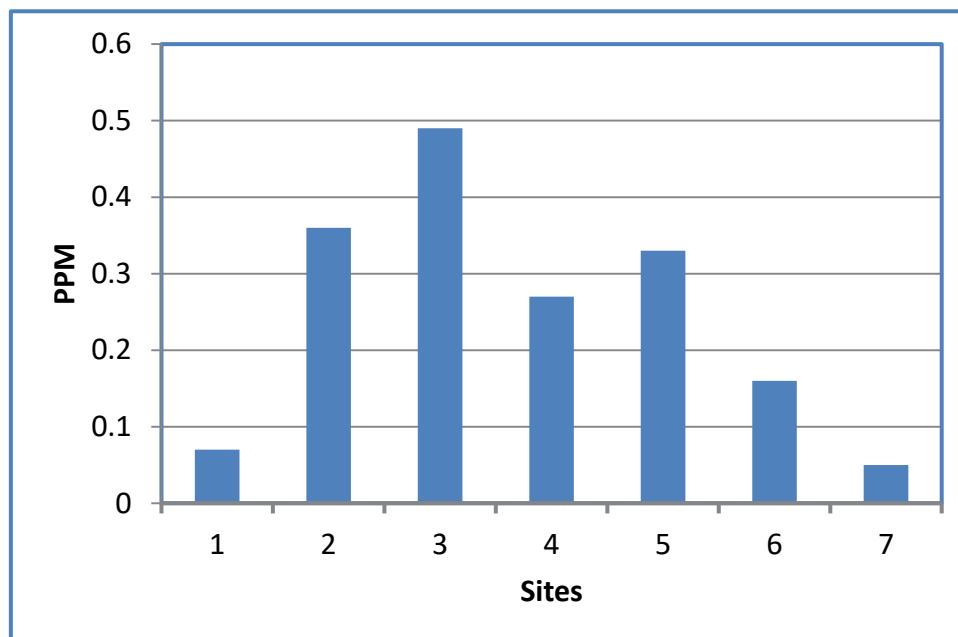


Figure 2. NO₂ concentration

3.3 Concentration of VOCs

Volatile organic compounds (VOCs) are defined as organic compounds with vapor pressure >0.01KPa at 293.15K (Iluțiu – Varvara et al., 2013). Exposure to VOCs may causes serious health effects such as skin, cardiovascular, eyes, liver, kidneys, gastrointestinal, respiratory system and central nervous system diseases. Additionally, VOCs are one of the

major contributors of the ozone formation, and subsequently photochemical smog.

High concentration of VOCs has been measured in all points, ranging from 324.09ppb in the loading area to 645.2 ppb in the casting area (Figure 3), indicating an increase by 39% and 177% in comparison with the ambient atmosphere (233ppb). Concentration of VOCs and other pollutants in the ambient atmosphere is attributed to the effect of the industrial city where the plant is located there. The most probable sources of VOCs in EAF process are: hydrocarbons contained in the scrap materials (plastic, paints, and foams), degreasing and decarburization of scrap, charging, tapping and slag pouring (Iluțiu – Varvara et al., 2013). In this study, scrap materials might be the main source of emissions, while less VOCs are produced during EAF operation. During cooling process, water spraying results in highly alkaline fumes which may causes serious air pollution (Iluțiu – Varvara et al., 2016). VOCs compounds consisting of tens of the organic compounds, so there is no specific limit for it, while there are many guidelines for some compounds such as benzene and formaldehydes.

Similarly, Iluțiu-Varvara et al.(2016), reported high concentration of VOCs in the melting stage in the EAF ranged from 2183ppm to 23368ppm from furnaces with capacity of 10 and 30 t respectively, and the emissions increased with time up to 110 minutes, and then decreased significantly with time (Iluțiu – Varvara et al., 2013). Odabasi, et al. (2009), found that the concentration of the organic compounds from the stack of steel plants with arc furnace technology, reached up to 611, 165000, and 33 ng/m³ for polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), and polybrominated diphenyl ethers (PBDEs) respectively (EC, 2018). Similarly, Gomes (2016) reported high VOCs emissions form steel production units having electric arc furnaces.

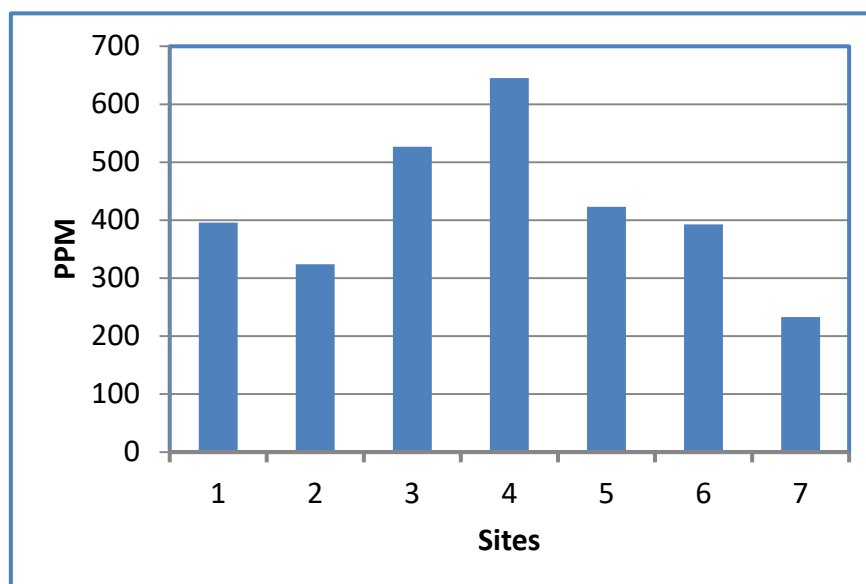


Figure 3. VOCs concentration

3.4 Concentration of Carbon Oxides

While CO₂ is considered the major contributor in climate change, CO has serious health effects forming carbon carboxyhemoglobin (COHB) resulting initially in symptoms of headache, nausea, dizziness, vomiting (at COHB =10%). Prolonged or high exposure period may causes coma and collapse (COHB=40%), and it is lethal at COHB level of 50-60%. To maintain COH <2.5%, WHO recommended CO concentration to be 90, 50, 25, and 10ppm for exposure time of 15m, 30m, 60m, and 8 hours respectively (Odabasi et al., 2009). OSHA standard limited TWA of CO₂ in workplace at 5000 ppm (WHO, 2000).

The concentration of CO was zero in all measure points. This could be explained by the high temperature of steel making process resulted in complete combustion and converting of CO to CO₂. In contrast, high CO₂ concentration was detected in all points ranged from 356ppm at slag pouring area to 410ppm at the casting area as shown in Figure 4. In comparison with the ambient air (317ppm), CO₂ inside the plant increased by 70, 39, 126, 177, 82, and 69% for the measured points respectively. Also high concentration was measured at the melting area (398ppm). Iluțiu – Varvara, et al. (2015), reported that the highest CO_x level inside the EAF occurred at the melting and at the beginning of the refining stage (EPA, 2009a). During melting and refining process, carbon is removed from the raw materials and converted to CO₂, which explains the high concentration at the melting and casting areas. Also, Argon-oxygen decarburization (AOD) process is a significant source of CO₂ generation. In AOD, Argon increases the affinity of carbon to O₂ resulted in high carbon removal and high oxides formation. At these concentrations of CO and CO₂ there is no occupational health effect is expected.

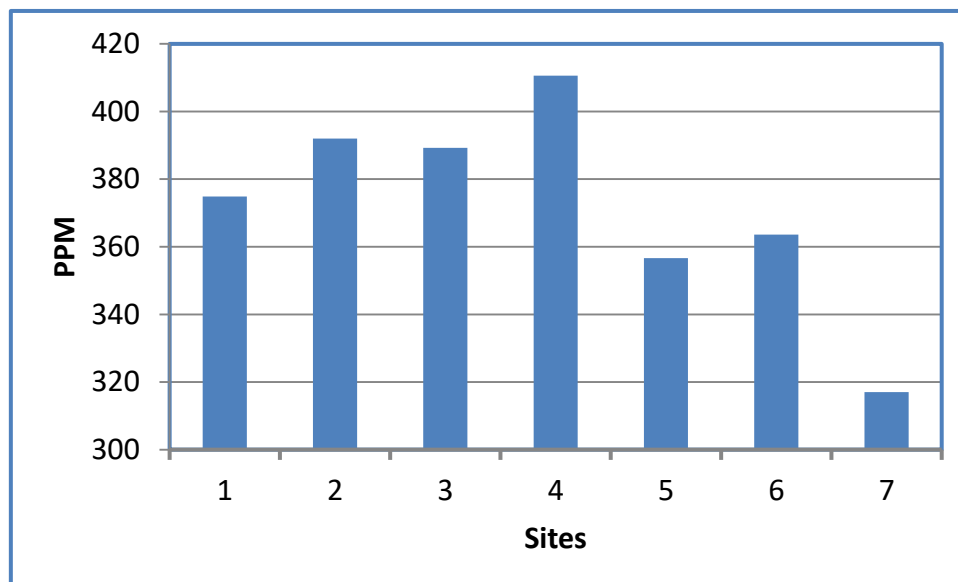


Figure 4. CO₂ concentration

3.5 Concentration of O₃

While, chemical reaction of NO_x, VOCs and sunlight is the major source of Ozone, it can

also be generated from many industries particularly the iron and steel industries. Environmentally, ozone is mainly responsible for photochemical smog formation. From the point of view health effect, it causes skin, eyes, nose and throat irritation, headache, vomiting, reduce lung function, inflame and damage cells that line lungs, aggravate asthma, and may cause permanent lung damage (Iluțiu – Varvara et al., 2015).

The concentration of O₃ in the steel making plant ranged from 0.026 at the casting area to 0.156ppm in the cooling area while it was 0.01 in the ambient atmosphere (Figure 5). Ozone formation depends on NO_x and VOCs, so positive concentration was detected in all points. Usually the point with the higher NO_x and VOCs level is the higher O₃, however this is not totally true because there is another factor affecting ozone formation i.e. the sunlight. Lower concentrations were measured in the covered area (melting, casting) where there is no sunlight which is necessary for O₃ formation, while high concentration was measured at the area exposed to sunlight (cooling).

In comparison with OSH standards of 0.1ppm as an average over 8hrs, the concentration s of ozone in the workplace has no health effect.

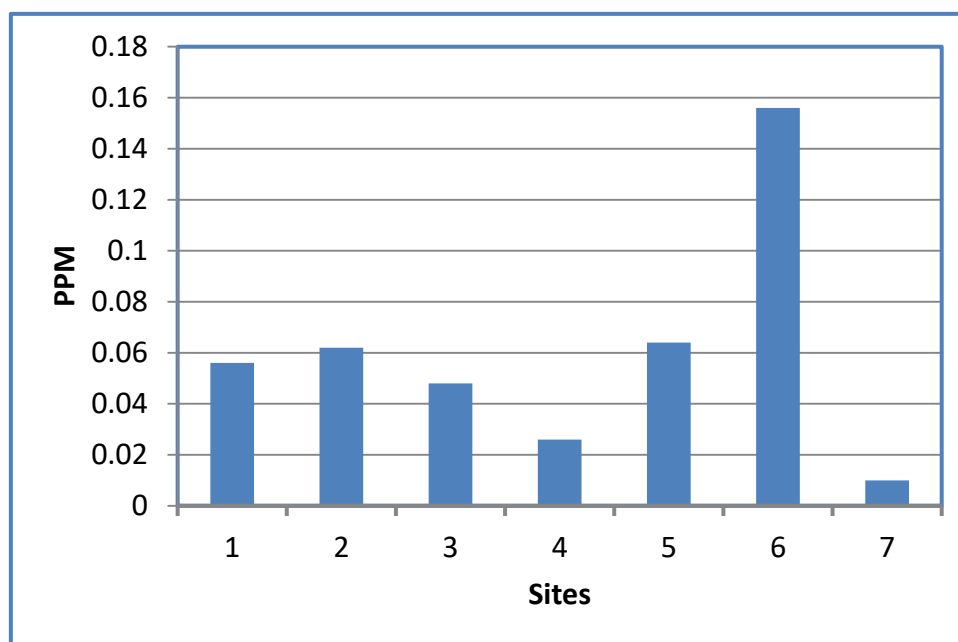


Figure 5. O₃ concentration

3.6 Concentration of PM₁₀ and PM_{2.5}

In steel making, dust is generated in different process, starting from storage of raw materials, handling, loading, charging, and melting, with lower level form next process. Dust is formed during the melting process. Typically, around 10 kg of dust generates per one ton of liquid steel (EPA, 2009b). Usually, dust contains many contaminants mainly iron oxides, calcium oxide, and zinc oxide. Additionally, dust may contain significant level of heavy metals such as: Al, Cd, Cr, Ni, Co, Cu and Pb.

The level and contents of the fugitive dust strongly depends on the scrap composition and types, furnace additives, efficiency of the control devices, and the measurements taken during storage and handling.

Survey of dust level indicated that the high concentration of PM₁₀ and PM_{2.5} were measured at the furnace area, reached 479 and 182 µg/m³ for both contaminants respectively (Figure 6, 7). Lower concentration were found in the slag area through pouring process (294, 25), also in the scrap area (195, 32) resulted from the handling and segregation process. Very low concentrations were measured in the loading area (28, 3), casting (17, 7) and cooling area (15, 1) where no source of dust emissions. Health effect of dust particularly depends on its constituent. WHO recommended PM₁₀ in the ambient air at 50 and 20 µg/m³ and for PM_{2.5} at 10 and 25 µg/m³ for 24-hours and annual mean respectively (Battle et al., 2014). In the scrap area, furnace area and the slag area, the concentration of PM₁₀ and PM_{2.5} exceeded WHO daily allowable limits for ambient air. The health effects of particulate matters (PM₁₀ and PM_{2.5}) are well documented, and there is no evidence of a safe level of exposure or a threshold below which no adverse health effects occur (WHO, 2005). For example, 3% of cardiopulmonary and 5% of lung cancer deaths are attributable to PM globally, and an increase in PM₁₀ by 10 µg/m³ will cause an increase in daily motility by 0.2-0.6%. The same increase (10 µg/m³) in PM_{2.5} will increase the mortality by 6-13% (WHO, 2005). It can be concluded that the high concentration of dust in the steel plant may cause high risk to the workers' health.

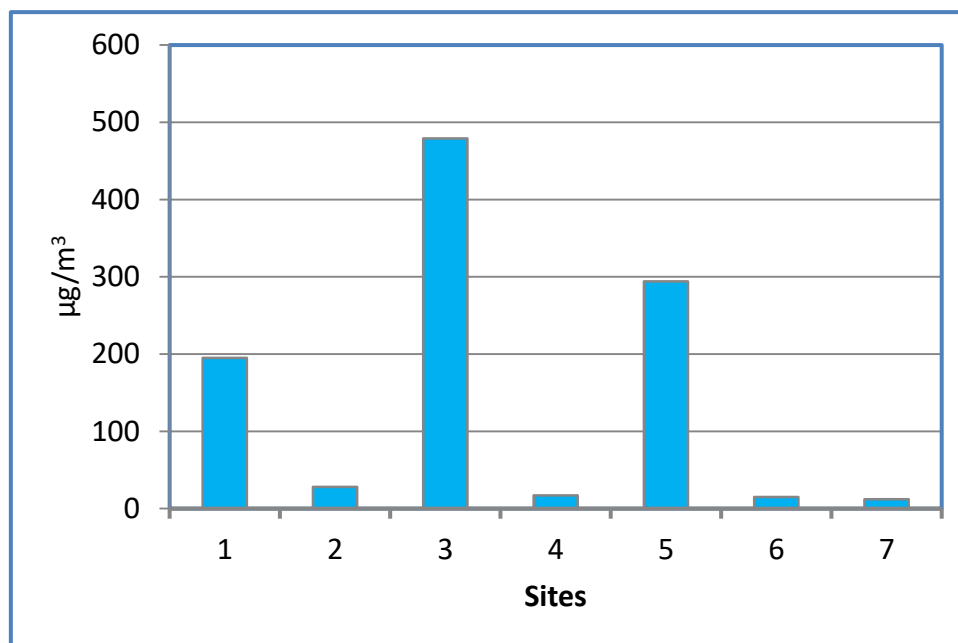


Figure 6. PM10 concentration

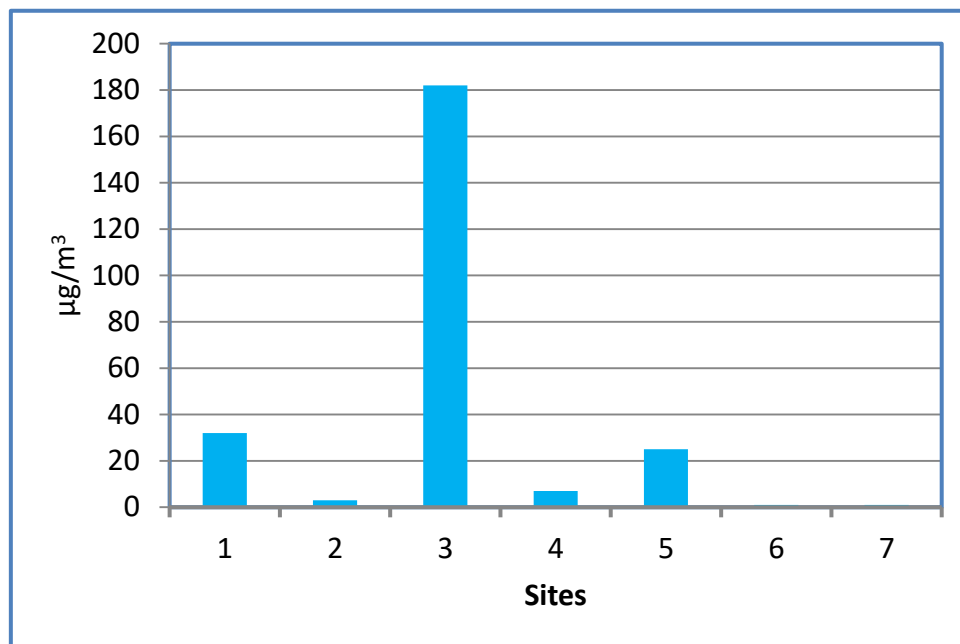


Figure 7. PM2.5 concentration

4. Conclusions

Indoor air quality in a steel making industry was evaluated through measurements of gases and particulate matters. The results obtained showed high concentration of indoor gases in comparison with the ambient air. High concentration of PM₁₀ and PM_{2.5} may cause potential health effect on workers. Types and contamination of scrap, performance of the control devices, environmental measurements are the key parameters in pollution reduction. Good ventilation and the atmospheric connection with the surrounding environment reduced the concentrations of pollutants inside the plant, and increase them in the environment. To reduce potential impacts on workers' health and the environment, it is recommended to:

1. Set a periodic medical check for workers especially lungs function.
2. Enforce workers to wear PPE.
3. Undertake industrial hygiene studies in order to evaluate the long-term effects of steel industries on human health.
4. Selection of uncontaminated scrap materials to be used in the industry.
5. Install adequate pollution control devices associated with routine maintenance.

Conflict of Interest

The authors certify that they have no affiliations with or involvement in any organization or entity with any financial interest, or non-financial interest in the subject matter or materials discussed in this manuscript.

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