Indoor Air Quality in Steel Rolling Industries and Possible Health Effects

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ARTICLE INFO

Received: 28 Dec 2018
Received in revised: 19 Apr 2019
Accepted: 2 May 2019
Published online: 13 Jun 2019
DOI: 10.32526/ennrj.17.4.2019.28

Keywords:
Air pollution/ Indoor air quality/ Steel industry/ Gases/ PM_{10}/ $PM_{2.5}$/ VOCs

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ABSTRACT

Indoor air quality has significant impacts on occupational health, workers' comfort and their productivity. The aim of this study was to assess indoor air quality in a rolling steel plant and to identify corrective measures that could help improve indoor air quality. Many air quality indicators, namely: CO, CO_2, VOCs, NOx, SO_2, O_3, PM_{10} and $PM_{2.5}$ were assessed as part of the study. The results obtained showed that higher concentrations of CO, VOCs, were found at the furnace area, while the rolling and quenching process area has the higher concentration of SO_2 and CO_2 respectively. PM_{10} and $PM_{2.5}$ exceeded the international standards in most of the measuring points. Potential negative health effects are expected due to the high temperature and VOCs at the furnace area in addition to the high particulate matters level in all points. Hazard indices (HI) were found to be >1 for all sites indicating possible health risk mainly due to the particulate matter. The respiratory system is the most affected organ, followed by cardiovascular system, then the eye irritation. Based on the potential health risks identified, the paper concludes with some recommendations for protecting workers' health. These include setting local standards for indoor air quality, applying job rotation strategy, periodical medical checks, good ventilation and conducting further studies concerning long-term effect of indoor air quality on occupational health.

1. INTRODUCTION

In 2017, the world steel production was 1.7 million tonnes (MT), of which 831 MT was produced in China, 168 MT in European countries, 104 MT in Japan and 101 MT in India (WSA, 2017). The steel industry has the highest energy requirement, resources consumption and environmental pollution. Its impact on ambient air quality is represented by huge quantities of gaseous emissions (SO_2, NO_2, VOCs, PCDD/Fs) and particulate matter. The steel industry is responsible for about 4-5% of total manmade greenhouse gases (Kundak et al., 2009).

The steel rolling process is one of the main resource intensive (e.g., energy consumption) parts of the steel production process. The rolling process aims to produce many steel products such as plate, rails, bars, wire, sheet, rods, seamless pipe, and coils. It has been reported that it generates significant environmental pollution, including indoor air pollution.

The initial rolling of steel is done in a hot rolling process, which needs high-energy consumption to deform the steel, overcome the frictional force, and losses in the pinions and motors. The pollution producing factors for hot rolling process are: 0.267, 0.28, 0.027, 0.034 kg/ton for SO_2, NOx, $PM_{2.5}$ and TSP, respectively, in comparison with 0.135, 0.08, 0.01, and 0.012 kg/ton in the cold process. Due to the high-energy consumption, the hot rolling process has higher impact on the environment against cold process, particularly on ambient air quality (Wu et al., 2015).

In the last couple of decades, significant technological development and advancement in air pollution control in the steel industry has meant that technologies such as ESP, scrubber, baghouse, and cyclone have been created with varying degrees of success in managing air pollution from steel factories and plants. Although there are positive impacts of these technologies, fugitive emissions are still a significant source of uncontrolled air pollution.

In addition to its impact on the ambient air quality, the steel industry causes serious impact on indoor air quality and occupational health. Typically, the areas immediately adjacent to steel making plants receive the most pollutants from the steel plants, with the concentrations of pollutants depending on the distance to the source and the meteorological conditions. It has been reported in the literature that up to 26% of the population living around steel plants suffer from respiratory diseases (Valenti et al., 2016). Unlike the ambient air, indoor air pollution has a high impact on the employees' health due to the high concentration of pollutants inside the plant, direct exposure, long times of exposure and high dosage of pollutants.

In 2014, about 500 injuries were recorded in the steel industry, with 5% of asthma cases attributed to soldering and welding activities. It was also reported that a large percentage of hearing loss was detected in ex and current steel employees (AWH, 2018). Rafiei et al. (2009), found a significant correlation between indoor air pollution in steel factories and occupational diseases. Generally, the relative risks (RR) of employees exposed to indoor air pollutants is higher than those for colleagues who are not exposed in relation to cardiovascular diseases (2.78), chest tightness (2.44), cough (2.15), difficulty in remembering (1.92), tension (1.57), occupational fatigue (3.90) and occupational stress (2.09 times).

Saudi Arabia has been ranked the 29^{th} international producer of steel and it is the leader of steel production in the gulf region with approximate production of crude steel of 4.8 million metric tons in 2016 (WSA, 2018). Due to the high number of employees in this industry and the potential environmental impacts, including indoor air pollution, the sector is increasingly the subject of more scrutiny from governmental and public environmental authorities.

In this paper, we assess indoor air pollution from a rolling steel plant in Jeddah Saudi Arabia. The results obtained from the analyses were interpreted in relation to potential human health risks, including occupational health. The outcomes of the research are used to formulate a series of recommendations for improvements based on lessons learned from other parts of the world or other sectors.

2. METHODOLOGY

2.1 Site location and characteristics

The plant is located in Jeddah in the western region of KSA with hot, humid weather in summer and moderate in winter. The average of maximum monthly temperature ranges from 30.2 in January to 38.7 °C in July, with minimums of 16.4 and 26 °C in February and August, respectively. The average annual precipitation is about 53.3 mm, mostly during the period from December to February. The prevailing wind is from the WNW with an average velocity of 18.4 km/h.

The plant uses already manufactured billets to produce construction steel rod bars through successive operations include: receiving billets, QC, heating (preheating, heating and soaking), descaling, roughing milling, quenching, intermediate milling, finishing milling, cooling, cut band, QC, weighting and storage of the produced bars. The plant only uses the hot rolling process which is performed to produce construction steel bars with different diameters (8, 10, 12, 14, 16, 18, 20 mm). The average daily production is about 3,900 tons. Since the production area is connected with ambient environment, the plant depends on natural ventilation in addition to fans connected with galvanized steel ducts at the furnace area with approximate total capacity of 320 m^3/min.

2.2 Instrumentations and measurements

As part of the study, portable devices were used to assess indoor air quality indicators, namely: CO, CO_2, VOCs, H_2S, NO_2, SO_2, O_3, humidity and temperature with respective detection ranges of 0-500 ppm, 0-10,000 ppm, 5-20,000 ppb, 0-50 ppm, 2.5-50, 0-30 ppm, 0-1 ppm respectively with accuracy of ±3% for each of the gaseous parameters. The instruments used were capable of taking samples every 10 sec and provide the average along the detection period of 15 min. An instrument was installed on a triangle stand at a breathing level of 1.5 m, a minimum of 2 m away from the nearest obstacles or the direct source of air pollution to avoid any potential interference during sampling (Darus et al., 2011). PM_{10} and $PM_{2.5}$ were measured simultaneously using dust profiler from Aeroqual using laser light scattering, capable of measuring and reporting data in 1 min intervals with detection range of 0-5,000 and 0-2,000 μg. All measurements were taken in triplicates during three successive days and the averages were reported. It worth mentioning here that the concentration of pollutants differ seasonally and weather dependent where wind and temperature changes play a significant role in the transportation and dispersion mechanism especially when there is direct connection between outside and inside environment due to the type of the steel industry.

Due to the limited process area in the plant, only five samples were taken in the areas most likely to be sources of pollution in the plant, i.e., furnace area (1), rolling (2), quenching (3), air cooling of final product (4). In addition, as a background reference, an extra measurement was taken at an ambient point (5) outside the plant.

2.3 Health risk assessment

The procedure of health risk assessment (HRA) aims to estimate the type and probability of the adverse effect of any pollutant on the receptors exposed to a certain level of air pollution. The hazard quotient (HQ) index is used to determine the health risk of non-carcinogenic substances. The HQ can be expressed as given in the following equation (Liu et al., 2015):

$$\mathrm{HQ} = \frac{\mathrm{C}}{\mathrm{Rfc}}$$

Where: HQ is the Hazard Quotient; C is the concentration of the pollutant measured (μg/m^3); and Rfc is the reference concentration at which the pollutant may cause no-carcinogenic health effect.

The HI index represents the summation of HQ_s for different pollutants that affect the same target organ. Cancer risk is defined as the number of new cancer cases per million people with 70 years lifetime. In case of inhalation exposure pathway, the cancer risk can be determined as following:

$$\mathrm{Risk} = \mathrm{C} \times \mathrm{UR}$$

Where: C is the concentration of pollutant (μg/m^3 or ppm); and UR is the unit of risk (μg/m^3 or ppm).

3. RESULTS AND DISCUSSION

3.1 Variation in concentrations along the sites

3.1.1 Temperature and relative humidity

Temperature and relative humidity (RH) are environmental parameters that can be used to asses work place comfort. High temperature and RH affect employee activity levels, can cause lethargy, lack of focus and increase in errors. Cold temperature in the workplace can cause low productivity, distraction and more errors. At high relative humidity, employees will feel warm, drowsy and sluggish, while at low RH, low moisture levels can cause dry and itchy skin, rashes, sore throat, and coughing.

Compared to the 36.4 ^{o}C ambient air temperature, recorded temperatures in the furnace, rolling, quenching and cooling areas were respectively recorded as 47.3±1.05, 42±1.09, 40±1.1, and 37.7±1.48 ^{o}C. These results indicate that the work activities have significant impact on the measured temperature. The heating process (furnace) caused an increase of the temperature by up to 30% in comparison with the ambient temperature. High temperature in the ambient air is due to the summer season in the study area as well as the impacts associated with the industrial city. High temperature inside the workplace in addition to the poor ventilation, adversely affected the pollutants dispersion and air mixing resulting in high concentration of indoor air pollutants. Relative humidity was 22.1, 24.3, 25.4, 27.0 and 32% for the measured points respectively. Statistical analyses indicated that there was significant spatial variation in the concertation of pollutants between all points at p-value of 0.05.

3.1.2 Carbon monoxide (CO)

CO concentration inside the plant reached 54, 22, 10, and 8 times of that measured in the ambient air for the furnace, rolling, quenching and cooling area respectively with average concentrations of: 5.4, 1.1, 1, 0.8, and 0.1 ppm and SD of 0.41, 0.08, 0.06, 0.06, and 0.007 respectively (Figure 1). A significant difference in the concentration along the different points was noticed, where the highest was at the furnace and the lowest was at the cooling area.

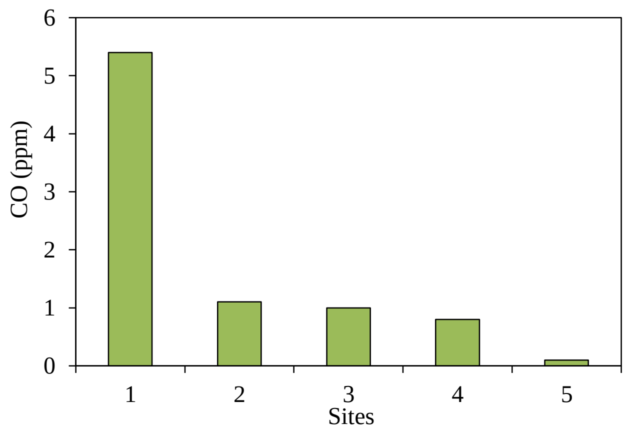

Figure 1. CO concentration

3.1.3 Carbon dioxide (CO_2)

In relation to CO_2 emission, the steel industry is considered one of the main sources where about 1.9 tonne of CO_2 is generated per one tonne of steel production (Kundak et al., 2009). At high temperature inside the furnace, carbon reacts with CO_2 to form carbon monoxide. In the hotter part of the furnace, carbon combustion produces CO, which is useful as a reducing agent for ferric oxide (Fe_2O_3) to produce iron (Fe). The negative impact of this process is the production of CO_2. In the rolling plant, the survey areas can be ranked according to their concentration of CO_2 as: rolling>quenching>furnace>cooling> ambient air. The average indoor concentration ranged from 520 to 635ppm represented an increase by: 14, 22, 19, and 3% in point 1, 2, 3, and 4 respectively (Figure 2). The calculated SD of CO_2 concentrations was 41.65, 50.8, 37.2, 37.6, and 36.40 for the measured points respectively.

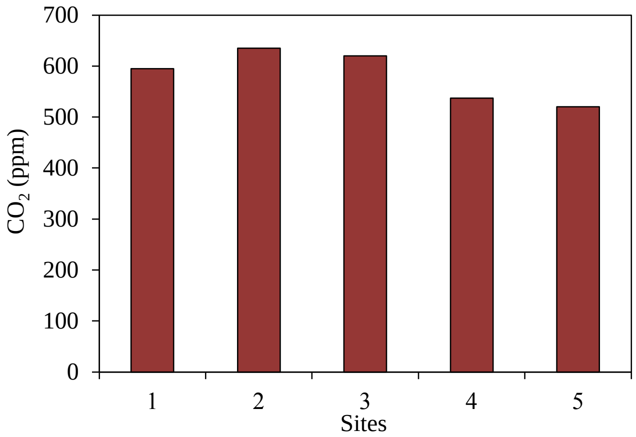

Figure 2. CO_2 concentration

3.1.4 Volatile organic compounds (VOCs)

The VOCs data showed spatial variation which ranged from 27 to 191 ppb, with average concentrations of 122, 82, 57, 55, 27 ppb, and SD of 7.30, 9.43, 3.42, 3.85, and 1.89 for the measured points respectively (Figure 3). The rate of increase was 350, 203, 111, 103% compared to the reference point (point 5). Concentration of VOCs and other pollutants in the ambient atmosphere is attributed to the effect of the industrial city where the plant is located. The high concentration of VOCs in the indoor environment of the plant could result from several sources, including hydrocarbon releases from the raw materials (scrap) used to make billets, high alkaline fumes (EC, 2013) from the quenching process, and lubricating oils for machines in the rolling process. High temperature inside the plant could increase the evaporation rate of the hydrocarbons compounds resulting in high fugitive emissions, mainly VOCs. This may be additional justification for the high VOCs in the furnace area. Other researchers have also reported that steel plants emit high concentrations of VOCs including polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), and polybrominated diphenyl ethers (PBDEs) (Odabasi, et al., 2009; Iluţiu-Varvara, 2016).

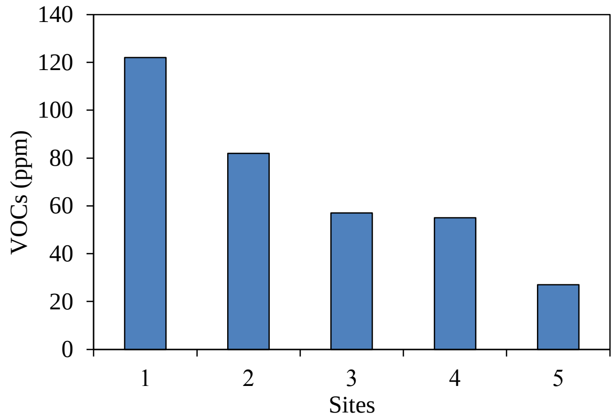

Figure 3. VOCs concentration

3.1.5 Nitrous oxides (NOx)

Another pollutant also emitted from steel factories are NOx, with reported rates of 0.12-0.32 kg/ton in the EAF process (Echterhof and Pfeifer, 2011). In the study area, the maximum average NO_2 concentration was at the furnace area (0.078 ppm) while the lowest one was 0.048 ppm at the cooling area (Figure 4) with very low SD (<0.005). Inside the plant, the concentration increased slightly with ratios of: 81, 27, 16, and 12% in comparison with the ambient point.

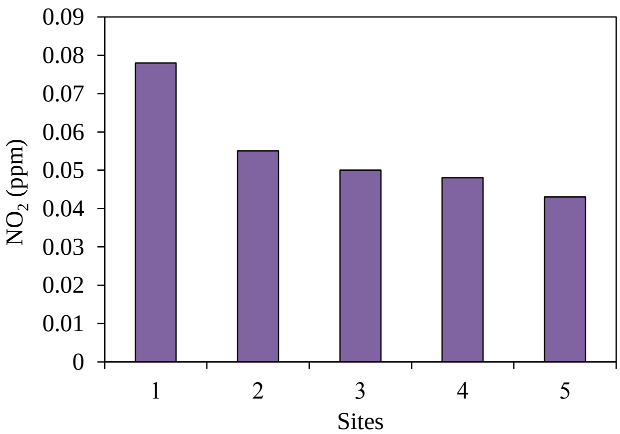

Figure 4. NO_2 concentration

3.1.6 Sulphur dioxide (SO_2)

The concentrations of SO_2 inside the plant ranged from 0.015 ppm in the furnace area to 0.07 ppm at the rolling area with SD values of 0.002, 0.006, 0.003, 0.002, and 0.0007 for the measured points respectively. In comparison with the ambient air, indoor SO_2 concentration increased by 36, 536, 400, 173% for the measured points respectively (Figure 5).

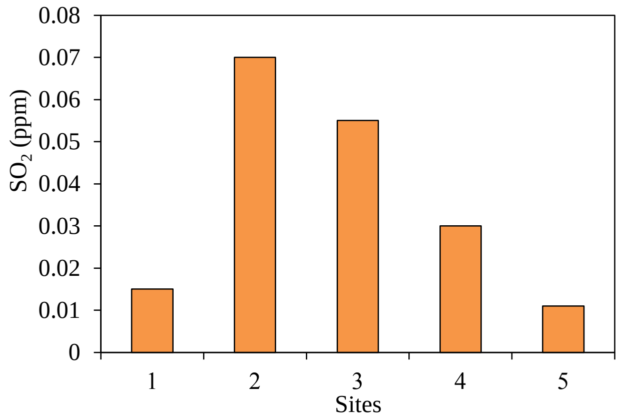

Figure 5. SO_2 concentration

3.1.7 Ozone (O_3)

In the ambient atmosphere, high concentration of O_3 is generally attributed to the presence of NOx, and VOCs in the ambient air, which react with sunlight to produce O_3. In the study area, ozone concentration ranged from 0.038 at the rolling area to 0.06 ppm in the ambient air (Figure 6) with SD less than 0.004 for all points. The significantly lower concentrations of O_3 inside the plant would be due to the absence of sunlight in the plant to catalyse the production of O_3.

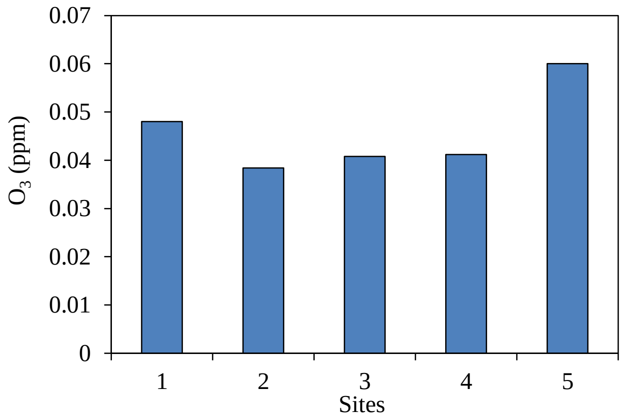

Figure 6. O_3 concentration

3.1.8 Hydrogen sulphide (H_2S)

Undetected concentration of H_2S was observed in all points. The results obtained would indicate that H_2S may not be an important contaminant of concern in the indoor environment of this specific steel plant.

3.1.9 Particulate matter

According to the European Commission, the emission factor of total suspended particulates (TSP) associated with steel production (specifically hot rolling processes) is 8.2 g/ton (EEA, 2016). In the study area, PM_{10} at the measured points ranged from 180 in the ambient air to 330 µg/m^3 in the furnace area (Figure 7) with SD values of 25.41, 22.0, 13.80, 14.35, and 12.60 for the measured points respectively. Similar to PM_{10}, the highest $PM_{2.5}$ concentration was detected in the furnace area while the lowest was in the ambient air. It can be concluded from the results that the rolling process resulted in an increase in PM_{10} by 83, 52, 27, and 13% with SD values of 2.93, 2.80, 1.56, 1.54, and 1.40 in the measured points respectively (Figure 7). In comparison with ambient air, $PM_{2.5}$ increased by 90, 75, 30, and 10% in the measured point's respectively. High concentration in the furnace area may be due to the high fumes in such area.

3.2 Standards and regulations

In the Kingdom of Saudi Arabia (KSA), there are no local standards for indoor air quality and this may affect the efforts in controlling and improving the indoor air quality in workplace and subsequently the occupational health. For this reason, it is necessary to define and implement local indoor air quality standards.

Table 1 below shows the concentration of the measured pollutants in each point as well as the applicable standards from Canada. The concentration of CO, CO_2, NO_2, SO_2, O_3 are far below the TWA standards for Ontario occupational health in workplace (OMOL, 2014). Compared to the regulatory standards, the reported VOCs concentrations in the furnace area were higher. At all other measuring points, the reported concentrations of VOCs were lower. PM_{10} at all measuring locations exceeded the allowable limit by: 120, 83, 53, 36, and 20% respectively. It is evident from the results that air quality measurements are affected by the high level of the atmospheric dust in KSA.

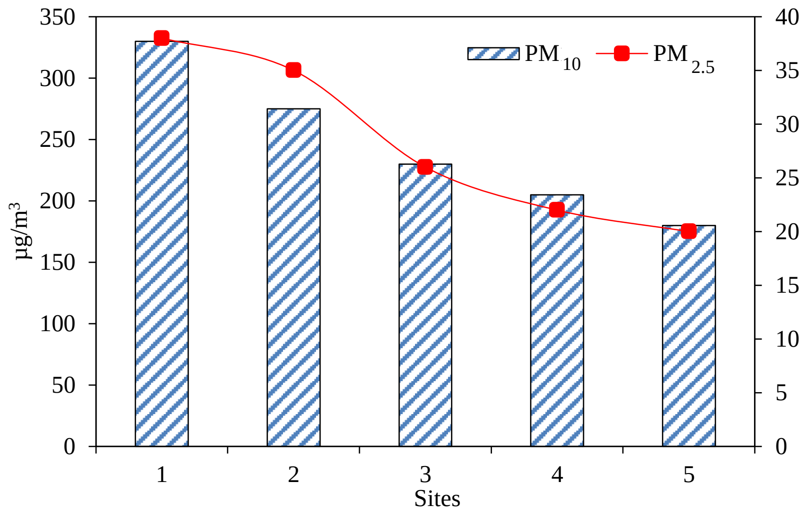

Figure 7. PM_{10} and $PM_{2.5}$ concentration

Table 1. Summary of pollutant concentrations against regulatory standards

Pollutant	Sampling locations within the steel plant					Standard TWA, STEL
	1	2	3	4	5	
CO	5.4	1.1	1	0.8	0.1	25,100*
CO_2	595	635	520	537	520	5,000, 30,000*
VOCs	122	82	57	55	27	120*x
NO_2	0.0778	0.055	0.05	0.048	0.043	3,5*
SO_2	0.015	0.07	0.055	0.03	0.011	2,5*
O_3	0.048	0.0384	0.0408	0.0412	0.06	0.1, 0.3*
PM_{10}	330	275	230	205	150	150+
$PM_{2.5}$	38	35	26	22	20	35+

*OMOL Reg 833; +NAAQS/EPA for 24 h; x: comfort limit (EPA, 1990); WHO (2005) recommended PM_{10} in the ambient air at 50 and 20 μm/m^3 and for $PM_{2.5}$ at 25 and 10 μm/m^3 for 24 h and annual mean respectively, TWA: time-weighted average, STEL: short-term exposure limits

3.3 Potential health hazard

3.3.1 Effect of CO

CO is a lethal gas generated mainly from incomplete combustion of carbonaceous compounds. Once absorbed via the lungs, it binds readily with blood hemoglobin forming carboxyhaemoglobin (COH). It has been reported that high COH levels in the bloodstream of humans pose significant health hazards such as headache, dizziness, nausea, and vomiting which could lead to collapse, coma and eventual death. In order to keep COH levels at <2.5%, the WHO recommends a safe CO concentration of 90, 50, 25, and 10 ppm for exposure time of 15 m, 30 m, 60 m, and 8 h, respectively (WHO, 2000). The field survey showed that the rolling process has high effect on CO concentration inside the plant, but all measurements are below the reported level of hazard.

3.3.2 Effect of CO_2

Carbon dioxide is a potent greenhouse gas contributing to climate change. CO_2 can also cause significant health effects. For example low concentration increases breathing rate slightly at concentration=1%, reached twice of normal breathing at concentration=3% and four times of the normal breathing at concentration=4-5%. At medium concentration (5-10%), workers are exposed to headache, unclear visual, and tinnitus, while a concentrations of 10-15%, a few minutes of inhalation will result in dizziness, drowsiness, and unconsciousness. At 30% concentration, it causes loss of control, unconsciousness, convulsion and death within one minute of inhalation. Higher concentrations may cause death within shorter time (WHO, 2000). Short and long-term exposure limit of CO_2 in the workplace as determined by the UK regulations at 15,000, and 5,000 ppm respectively (CCS, 2018). In this study, it was reported that in the furnace and rolling areas, all concentration are ≤635 ppm (0.635%) which are far below the concentrations which could have potential health impacts on employees.

3.3.3 Effect of VOCs

VOCs are organic compounds generated from controlled or uncontrolled sources in the steel industries. The effect of VOCs on human health depends particularly on the type of the compound as well as the dosage and the exposure time. The initial symptoms of VOCs inhalation include discomfort of throat and nose, dyspnea headache, irritation of skin, fatigue, and dizziness. High dosage may lead to loss of coordination, and damage to liver, kidney, and the central nervous system (EPA, 2017; Al-Zboon and Forton, 2019). Since there are thousands of VOCs, no standards have been set, while there are standards for some compounds which health risks such as formaldehyde. OMOL (2014), reported that a concentration of 12 ppb has no irritation or discomfort effect on worker's health, while concentration of 120-1,200 ppb has cause many symptoms including irritation, discomfort, and stress. In this study, the measured VOCs concentrations in the workplace are below the limit of 120 ppb except at furnace area, which slightly exceeded this limit (122 ppb), indicating that nonegative health impacts are expected. However, to minimise any potential impacts of VOCs on the employees' health, it is necessary to provide workers with the required PPE, periodical rotation of workers between different sections to decrease the accumulative personnel health impact. In addition, workers should be subjected to an annual medical check.

3.3.4 Effect of NO_2

Reheating of steel products at elevated temperatures is a major source of NOx emissions in the steel industry. Based on mechanism of formation and the high furnace temperature, fugitive NOx emissions could either be defined as: thermal NOx, fuel NOx, and prompt NOx (Chan et al., 2004; Kirschen et al., 2005). In the literature, it has been reported that at low concentration (0.1-0.12) of NO_2 and short exposure time (1 h), no health effect can be observed on the specific airway conductance (SGaw), specific airway resistance (SRaw), forced expiratory volume (FEV1) and carbachol reactivity. High concentration may cause significant health effects even with short exposure time. For example, a concentration of 1.6 ppm can result in an increase in airway resistance (Raw) during 15 min while a concentration of >4 ppm decreased the partial pressure of oxygen (PO_2). Similarly, long exposure time (4 h) with low concentration (0.3 ppm) causes serious functional effects on patients with chronic obstructive pulmonary disease (WHO, 2000)

Regarding occupational health effects, high levels of NOx may cause shortness of breath, affect the oxygen carrying capability of blood, cause fatigue, dizziness, blue skin and lips colour and may lead to lung damage. According to OSHA, the recommended exposure limit in workplace is 5 ppm, while ACGIH recommended 3 and 5 ppm for 8 h and 15 min exposure time. A stricter limit of 1ppm has been set by NIOSH (NJDHSS, 2000). Most of the reported studies in the literature show that there is no health effect at a concentration <0.12 ppm which indicates that at the current level of NOx in the rolling steel industry (<0.078 ppm) no occupational health hazards are expected.

3.3.5 Effect of SO_2

Inhalation of SO_2 can affect human health with symptoms such as nose, throat, airways and eyes irritation. High doses or long exposure times may result in lung damage and death (Iluțiu-Varvara et al., 2013). Negative impacts of SO_2 inhalation typically depends on the dosage and the sensitivity of the receiver. Generally the symptoms appear shortly on most people within 10-15 min after exposure (DOEE, 2005). It has been reported that a concentration of 100 ppb causes changes in airways resistance, while a concentration of 400 ppb results in a change in the lung function (WHO, 2000). The WHO recommends that a concentration of 0.175 ppm should not be exceeded over an exposure period of 10 min, 0.04 for 24 h, and 0.019 ppm/year (WHO, 2000).

3.3.6 Effect of O_3

It has been reported in the literature that at O_3 concentrations of 50-70 $\mu g/m^3$, mortality increases significantly during 1-8 h exposure time. Due to the high concentration of O_3 in the atmosphere, about 990 persons died in the Netherlands during June-August 2000 (WHO, 2010). Low concentration may cause irritation an individual's respiratory system, uncomfortable breathing, reduce lung function, inflame and damage cells that line your lungs, and permanent lung damage (EPA, 2014).

All measurements inside the plant are below OSHA standards for workplace of 0.1 ppm as an average over 8 h and it can be concluded that within the steel plant for this study, no health effect related to ozone are anticipated.

3.3.7 Effect of PM_{10} and $PM_{2.5}$

Negative impacts of dust particulate depend mainly on the constituents of these particles. Depending on its source, particulate matters may contain a wide range of compounds and elements such as sulphate, nitrate, silicates, sodium chloride, chloride, calcium chloride, zinc oxide, organic carbon, polycyclic aromatic hydrocarbons (PAH), heavy metals, and biological issues.

Smaller dust particles (≤10 µm) penetrate the thoracic part of the respiratory system. Many researchers have reported the correlation between many diseases and dust level. For example, it was reported that particulate matter (PM_{10} and $PM_{2.5}$) are responsible for some respiratory diseases such as aggravation of asthma, irritation, increase hospital admissions, and increase the daily mortality up to 6-13% with 10 µm/m^3 increase in $PM_{2.5}$. It was reported that 1,290 persons died in the Netherlands during June-August 2000 due the high concentration of PM (WHO, 2010). In many cities around the world, reported decreases in mortality cases have been associated with decreased concentrations of particulate matter (PMs) in the atmosphere (WHO, 2005).

In comparison with WHO limit for PM_{10} (50 µm/m^3 for 24 h), all sites in the plant had a concentration above the standard limit which may have a negative effect on workers' health. Similarly, $PM_{2.5}$ concentrations were higher than the WHO standards (10 µm/m^3).

High concentrations of particulate matter raise the necessity to provide the workers with the required masks and to enforce them to wear it. Annual medical checks are necessary, especially for persons who are working in the furnace area. It is also necessary to conduct a training program concerning the hazards of indoor air pollution.

3.4 Health risk assessment

Table 2 shows the HQ values for each pollutant at each site within the plant. It has been reported in the literature that if the HQ or HI≥1, it indicates a potential health risk associated with exposure to contaminants (Liu et al., 2015). In the present study, the values of HQ for CO_2, VOCs, NO_2 and O_3 were <1 in all sites indicating limited potential for significant health impacts from each pollutant when considered individually. High HQ values (>1) for PM_{10} were found in all sites while HQ of $PM_{2.5}$ was >1 only in site 1 (furnace area) and 2 (rolling area). The summation of the HQ is expressed as hazard index (HI) were found to be >1 for all sites indicating possible health risk mainly due to the particulate matters.

Table 2. HQ values for indoor air quality

Sampling location within the plant	Pollutant							HI
	CO_2	VOCs	NO_2	SO_2	O_3	PM_{10}	$PM_{2.5}$	
1 (furnace area)	0.12	0.22	0.34	0.06	0.52	4.40	1.09	6.75
2 (rolling area)	0.13	0.15	0.24	0.30	0.42	3.67	1.00	5.90
3 (quenching)	0.12	0.10	0.22	0.24	0.44	3.07	0.74	4.94
4 (air cooling of final product)	0.11	0.10	0.21	0.13	0.45	2.73	0.63	4.36
5 (ambient air)	0.10	0.05	0.19	0.05	0.45	2.40	0.57	3.81

To determine the target organs, it was supposed that NO_2, SO_2 and PM_{10} have health effect on the respiratory system. In addition to the respiratory system, VOCs have effects on the nervous system, haematological system and allergy infections. Ozone has health effects on the respiratory system and eyes, while $PM_{2.5}$ has an effect on the cardiovascular system (OEHHA, 2015). Based on these indicators, the health risks estimated from each of the measuring locations within the plant is presented in Table 3.

As shown in Table 3, it is clear that the respiratory system is the most affected organ, followed by the cardiovascular system, then eye irritation. Site 1 (the furnace) has the highest value of HI for all target organs indicating high health risk in this site especially for the respiratory system. OEHHA (2015), determined the unit risk for many VOCs compounds ranged from 0.264 for carbon tetrachloride to $3.47x10^{-5}$ for dichlorobenzene, but there is no risk factor for combined VOCs. For an average unit risk of 0.0268/1 ppm, the total calculated risk of VOCs inside the plant is respectively 0.0033, 0.0022, 0.0015, 0.0015 and 0.0007 for site 1 (furnace area), 2 (rolling area), 3 (quenching), 4 (air cooling of final product), and 5 (ambient air), respectively. These values exceeded the acceptable limit ($1x10^{-4}$ to $1x10^{-6}$) (Liu et al., 2015).

Table 3. Hazardous index of indoor air quality on human health

Sampling location within the plant	Respiratory system	Nervous system	Cardiovascular system	Eye irritation	Allergy; infection	Hematological system
1 (furnace area)	5.55	0.22	1.09	0.74	0.22	0.22
2 (rolling area)	4.77	0.15	1.00	0.56	0.15	0.15
3 (quenching)	4.07	0.10	0.74	0.55	0.10	0.10
4 (air cooling of final product)	3.62	0.10	0.63	0.55	0.10	0.10
5 (ambient air)	3.13	0.05	0.57	0.50	0.05	0.05

5. CONCLUSION

In this paper, indoor air quality inside a steel rolling plant in Jeddah, KSA was assessed using portable monitoring devices. Concentration of CO, CO_2, VOCs, NOx, SO_2, O_3, PM_{10} and $PM_{2.5}$ were measured during three successive days in the furnace area, rolling, quenching, and cooling sites. The results showed a significant impact of the rolling process on indoor air quality especially at the furnace area. In comparison with the ambient air, higher concentration were found for CO (400%), CO_2 (22%), VOCs (350%), NOx (81%) SO_2 (536%), and PM_{10} (83%). The type and concentration of pollutants recorded varied spatially and temporally and was dependent on the type of the active operation and the specifications of the workplace. The highest concentrations of CO, VOCs, NO_2, PM_{10}, and $PM_{2.5}$ were recorded in the furnace area while the highest SO_2 concentration was detected at the rolling area. High concentrations of fugitive emissions, especially VOCs, PM_{10}, $PM_{2.5}$ and high temperature require necessary actions to mitigate negative impacts on employees' health. The health risk assessment indicated that the emissions from the steel rolling plant mostly affect the respiratory system.

REFERENCES

Al-Zboon K, Forton O. Indoor air quality in steel making industries. Environmental Management and Sustainable Development 2019;8(1):147-79.

AWH Solicitors. What are the occupational risks of working in the steel industry [Internet]. 2018 [cited 2018 September 18]. Available from: https://awhsolicitors.co.uk/ articles/industrial-disease/occupational- risks- steel-industry.

Carbon Capture and Storage Institute (CCS). General hazards associated with CO_2 [Internet]. 2018 [cited 2018 July 25]. Available from: https://hub.globalccsinstitute.com/ publications/ hazard - analysis - offshore-carbon - capture - platforms - and - offshore - pipelines /32-general-hazards-associated-co2.

Chan E, Riley M, Thomson M, Evenson E. Nitrogen oxides (NOx) formation and control in an electric arc furnace (EAF): Analysis with measurements and computational fluid dynamics (CFD) modeling. ISIJ International 2004;44(2):429-38.

Department of the Environment and Energy Australia (DOEE). Sulphur dioxide [Internet]. 2005 [cited 2018 July 22]. Available from: http://www.environment.gov.au/protection/publications/factsheet-sulfur-dioxide-so2.

Darus F, Zain-Ahmed A, Latifc M. Preliminary assessment of indoor air quality in terrace houses. Health and the Environment Journal 2011;2(2):8-14.

Echterhof T, Pfeifer H. Measurement and control of NO_x emissions at two AC electric arc furnaces. ISIJ International 2011;51(10):1631-6.

European Environmental Agency (EEA). Air Pollutant Emission Inventory Guidebook 2016. Luxembourg: Publications Office of the European Union; 2016.

Environmental Protection Agency (EPA). National ambient air quality standards [Internet]. 1990 [cited 2018 September 21]. Available from: https://www.epa.gov/criteria-air-pollutants/naaqs-table.

United States Environmental Protection Agency (U.S. EPA). Air Quality index: A Guide to Air Quality and Your Health. North Carolina, USA: Environmental Protection Agency; 2014.

Environmental Protection Agency (EPA). Volatile organic compounds' impact on indoor air quality [Internet]. 2017 [cited 2018 July 24]. Available from: https://www.epa.gov/indoor-air-quality-iaq/volatile-organic-compounds-impact-indoor-air-quality.

Iluțiu-Varvara D, Brânduşan L, Pică E. Researches regarding the air pollution with sulfur dioxide (SO_2) to the steelmaking. Advanced Engineering Forum 2013;8-9:115-26.

Iluţiu-Varvara D, Mârza C, Aciu C, Hădărean A, Domniţa F, Sas-Boca I, Mihu A. An assessment of pollution with volatile organic compounds in the electric arc furnaces. Procedia Technology 2016;22:45-6.

Kirschen M, Voj L, Pfeifer H. NO_x emission from electric arc furnace in steel industry: Contribution from electric arc and co-combustion reactions. Clean Technologies and Environmental Policy 2005;7(4):236-44.

Kundak M, Lazic L, Crnko J. CO_2 Emissions in the steel industry. Metalurgija 2009;48(3):193-7

Liu K, Yeh K, Hung M, Chen C, Shen Y. Health risk analysis of indoor air pollution. International Journal of Environmental Science and Development 2015;6(6): 464-8.

New Jersey Department of Health and Senior Services (NJDHSS). Hazardous Substances Fact Sheet. New Jersey, USA: New Jersey Department of Health and Senior Services; 2000.

Odabasi M, Bayram A, Elbir T, Seyfioglu R, Dumanoglu, Bozlaker A, Demircioglu H, Altiok H, Yatkin S, Cetin B. Electric arc furnaces for steel-making: Hot spots for persistent organic pollutants. Environmental Science and Technology 2009;43(14):5205-11.

Office of Environmental Health Hazard Assessment (OEHHA). OEHHA acute, 8-hour and chronic reference exposure level (REL) summary [Internet]. 2015 [cited 2019 April 1]. Available from: https://oehha.ca.gov/air/general-info/oehha-acute-8-hour-and-chronic-reference-exposure-level-rel-summary.

Ontario Ministry of labour (OMOL). Current occupational exposure limits for ontario workplaces required under regulation 833 [Internet]. 2014 [cited 2018 July 22]. Available from: https://www.labour.gov.on.ca/english /hs/pubs/oel_table.php.

Rafiei M, Gadgil AS, Ghole VS, Gore SD, Jaafarzadeh N, Mirkazemi R. Assessment of air pollution and its effects on the health status of the workers in beam rolling mills factory (Iran National Steel Industrial Group) from Ahvaz-Iran. The Indian Journal of Occupational and Environmental Medicine 2009;13(1): 20-2.

Valenti C, Pozzi P, Busia A, Mazza R, Bossi P, Marco C, Rupretch A, Borgini A, Boffi R. Respiratory illness and air pollution from the steel industry: The case of Piquiá de Baixo, Brazil. Multidisciplinary Respiratory Medicine 2016;11(41):1-7.

World Healt Organization (WHO). Air Quality Guidelines for Europe. 2nd ed. Copenhagen, Denmark: WHO Regional Publications; 2000.

World Healt Organization (WHO). Air Quality Guidelines for Particulate Matter, Ozone, Nitrogen Dioxide and Sulfur Dioxide. Geneva, Switzerland: World Health Organization Press; 2005.

World Health Organization (WHO). Health Risks of Ozone From Long-Range Transboundary Air Pollution. Copenhagen, Denmark: WHO Regional Publications; 2010.

World steel Association (WSA). Steel Statistical Yearbook. Brussels, Belgium: World Steel Association; 2017.

World steel Association (WSA). World steel in figures 2018. Brussels, Belgium: World Steel Association; 2018.

Wu X, Zhao L, Zhang Y, Zheng C, Gao X, Cen K. Primary air pollutant emissions and future prediction of iron and steel industry in china. Aerosol and Air Quality Research 2015;15:1422-32.