Indoor Air Quality in Steel Rolling Industries and Possible Health Effects

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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, CO2, VOCs, NOx, SO2, O3, PM10 and PM2.5 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 SO2 and CO2 respectively. PM10 and PM2.5 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 (SO2, NO2, 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 SO2, NOx, PM2.5 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 29th 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 m³/min.

2.2 Instrumentations and measurements

As part of the study, portable devices were used to assess indoor air quality indicators, namely: CO, CO₂, VOCs, H₂S, NO₂, SO₂, O₃, 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). PM₁₀ and PM₂.5 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):

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

Where: HQ is the Hazard Quotient; C is the concentration of the pollutant measured (µg/m³); and Rfc is the reference concentration at which the pollutant may cause no-carcinogenic health effect.

The HI index represents the summation of HQs 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:

$$Risk = C \times UR$$

Where: C is the concentration of pollutant (µg/m³ or ppm); and UR is the unit of risk (µg/m³ 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 assess workplace 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 °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 °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 concentration 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.

3.1.3 Carbon dioxide (CO₂)

In relation to CO₂ emission, the steel industry is considered one of the main sources where about 1.9 tonne of CO₂ 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$_2$O$_3$) 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 655ppm 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](image)

### 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](image)

### 3.1.5 Nitrous oxides (NO$_x$)

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](image)

### 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](image)

### 3.1.7 Ozone (O\(_3\))

In the ambient atmosphere, high concentration of O\(_3\) is generally attributed to the presence of NO\(_x\), 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](image)

### 3.1.8 Hydrogen sulphide (H\(_2\)S)

Undetected concentration of H\(_2\)S was observed in all points. The results obtained would indicate that H\(_2\)S 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.
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*          |
| CO₂       | 595 | 635 | 520 | 537 | 520 | 5,000, 30,000*   |
| VOCs      | 122 | 82  | 57 | 55  | 27  | 120*             |
| NO₂       | 0.0778 | 0.055 | 0.05 | 0.048 | 0.043 | 3.5*           |
| SO₂       | 0.015 | 0.07 | 0.055 | 0.03 | 0.011 | 2.5*           |
| O₃        | 0.048 | 0.0384 | 0.0408 | 0.0412 | 0.06 | 0.1, 0.3*       |
| PM₁₀      | 330 | 275 | 230 | 205 | 150 | 150+            |
| PM₂.₅     | 38  | 35  | 26  | 22  | 20  | 35+             |

*OMOL Reg 833; +NAAQS/EPA for 24 h; x: comfort limit (EPA, 1990); WHO (2005) recommended PM₁₀ in the ambient air at 50 and 20 µg/m³ and for PM₂.₅ at 25 and 10 µg/m³ 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 CO₂

Carbon dioxide is a potent greenhouse gas contributing to climate change. CO₂ 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 CO₂ 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 nonnegative 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 NO₂

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; Kirschchen et al., 2005). In the literature, it has been reported that at low concentration (0.1-0.12) of NO₂ 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 (PO₂). 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 SO₂

Inhalation of SO₂ 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 (Iluju-Varvara et al., 2013). Negative impacts of SO₂ 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 O₃

It has been reported in the literature that at O₃ concentrations of 50-70 μg/m³, mortality increases significantly during 1-8 h exposure time. Due to the high concentration of O₃ 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\textsubscript{10} and PM\textsubscript{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\textsubscript{10} and PM\textsubscript{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\textsuperscript{3} increase in PM\textsubscript{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\textsubscript{10} (50 µm/m\textsuperscript{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\textsubscript{2.5} concentrations were higher than the WHO standards (10 µm/m\textsuperscript{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\textsubscript{2}, VOCs, NO\textsubscript{2} and O\textsubscript{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\textsubscript{10} were found in all sites while HQ of PM\textsubscript{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\textsubscript{2} | VOCs | NO\textsubscript{2} | SO\textsubscript{2} | O\textsubscript{3} | PM\textsubscript{10} | PM\textsubscript{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\textsubscript{2}, SO\textsubscript{2} and PM\textsubscript{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\textsubscript{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. OEHHHA (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, CO₂, VOCs, NOx, SO₂, O₃, PM₁₀ and PM₂.₅ 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%), CO₂ (22%), VOCs (350%), NOx (81%) SO₂ (536%), and PM₁₀ (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, NO₂, PM₁₀ and PM₂.₅ were recorded in the furnace area while the highest SO₂ concentration was detected at the rolling area. High concentrations of fugitive emissions, especially VOCs, PM₁₀, PM₂.₅ 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.

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