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RESEARCH ARTICLE

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Particulates and carbon monoxide pollution on production floor of steel recycling plant

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Abstract

For this study, particulates or particulate matter (PM) and carbon monoxide (CO) levels were monitored at different sections on the production floor of a scrap metal recycling factory. A Met-One GT331 dust monitor and A Toxi-Rae gas monitor were used to measure PM and CO concentrations, respectively. The 24-hr averaging period concentrations of particulate matter having diameters of 2.5 microns or less in diameter ($PM_{2.5}$), particulate matter having diameters of 10 microns or less in diameter (PM_{10}), and total suspended particulates (TSP) within the plant ranged between 8.3 and 50.4 $\mu g/m^3$, 12.0 and 151.3 $\mu g/m^3$, and 30.0 and 285.0 $\mu g/m^3$, respectively, while the maximum 8-hr concentration of CO within the plant was 20.5 parts per million (ppm). The United States' Environmental Protection Agency (US EPA) limits for $PM_{2.5}$, PM_{10}, and CO were exceeded only in the area around the furnace. Nigeria's Federal Ministry of Environment (FMENV), the World Health Organization (WHO), and the World Bank statutory limit for TSP were also exceeded in the area around the furnace. Toxicity potentials (TP) of the investigated pollutants were greater than 1.0 around the furnace, indicating that work spaces in proximity to the furnace could expose workers to adverse health conditions.

KEYWORDS
air quality index, recycling industry, scrap metal, toxicity potential, workplace

1 | INTRODUCTION

The steel recycling process involves collecting discarded metal; cutting and shearing large scraps into manageable sizes; melting the scrap in a furnace; molding molten metal into billets through a series of casting machines; reheating in an oven; rolling into desired, smaller steel rods of different sizes; and loading for sales. The economic benefits of steel recycling cannot be downplayed. Steel recycling is even more important in the developing countries, such as Nigeria, where the unemployment rate is high. Another benefit of steel recycling from the environmental point of view includes getting keeping steel scraps out of the environment. When goods made of steel, such as car bodies, are dumped in the environment, car bodies, which should be a major source of raw material if recycled, can instead leach toxic chemicals from oil, petrol, diesel fuel, coolants, and transmission and brake fluids. They can also leach battery acid. Junk cars dumped in rivers can become lethal traps for swimmers and for wildlife, and chemicals in scrap metal dumped in the bush can combust causing wildfires. Furthermore, uncontrolled dumping sites tend to create additional solid waste management problems.

While steel recycling plants provide a lot of advantages, their various processes constitute potential sources of occupational exposure. Occupational exposure to pollutants is distinct in that it is, by definition, associated with the workplaces where workers spend most of their time, and is therefore the responsibility of employers. The various processes associated with recycling scrap metals are characterized by the emission of air pollutants. Airborne PM is generated during the shearing of metals at the scrapyard and during melting in the furnace. Various studies have linked respiratory diseases with the inhalation of PM (Miri, Ahmadi, Ghanbari, & Moghaddamnia, 2007; Otto et al., 2007; Sacks et al., 2010). In addition to particulate, the melting of scraps in the furnace also produces CO from the incomplete combustion of carbon. CO is readily absorbed from lungs into the bloodstream, resulting in competitive bonding between it and oxygen to hemoglobin in the red blood cell, forming carboxyhemoglobin and oxyhemoglobin, respectively. The carboxyhemoglobin causes decreased oxygen carrying capacity of the blood, thus inducing toxic effects which are dangerous to human health (Sonibare, 2010).

TP is usually used to describe the possible negative health impact that an air shed may pose as result of the pollutants it contains. TP has been defined as the ratio of observed gross concentrations of pollutants to the statutory limit set for ambient concentrations (Fakinle, Sonibare, Akeredolu, Okedere, & Jimoda, 2013). While workplace pollution involving criteria pollutants is receiving serious attention in developed countries, there exists a data gap in the developing countries.

This study was carried out to assess the levels of pollution in one of Nigeria's scrap metal recycling facilities. Concentrations of PM and CO were used as indicators of pollution. The impetus for this work is to raise the level of awareness among stakeholders (e.g., government, investors, and workers) in the industry regarding the need to develop and enforce compliance with safety measures.

EXHIBIT 1 Measured 24-hr concentrations of $PM_{2.5}$

	Concentration of $PM_{2.5}$ (μg/m^3)			
Factory section	**Day 1**	**Day 2**	**Day 3**	**Mean**
Scrap yard	16.5	18.4	17.9	17.6
Furnace	41.1	52.5	57.7	50.4
Billet	11.5	12.3	11.8	11.9
*Rh-oven	14.9	16.8	16.3	16.0
Rolling	9.7	10.2	9.1	9.7
Loading	8.3	7.9	8.7	8.3

*Re-heating oven.

EXHIBIT 2 Measured 24-hr concentrations of PM_{10}

	Concentration of PM_{10} (μg/m^3)			
Factory section	**Day 1**	**Day 2**	**Day 3**	**Mean**
Scrap yard	33.2	40.5	37.9	37.2
Furnace	123.3	170.5	160.2	151.3
Billet	28.9	34.7	31.6	31.7
*Rh-oven	25.3	31.9	29.2	28.8
Rolling	15.3	17.2	16.1	16.2
Loading	12.6	10.1	13.2	12.0

*Re-heating oven.

EXHIBIT 3 Measured 24-hr concentrations of TSP

	Concentration of TSP (μg/m^3)			
Factory section	**Day 1**	**Day 2**	**Day 3**	**Mean**
Scrap yard	51.5	60.5	58.3	56.8
Furnace	287.7	267.2	300.1	285.0
Billet	41.5	50.3	40.8	44.2
*Rh-oven	38.8	32.5	43.5	38.3
Rolling	49.3	56.7	50.2	52.1
Loading	3 4.0	32.3	25.1	30.5

*Re-heating oven.

2 | MATERIALS AND METHODS

2.1 | Measurement of air quality parameters ($PM_{2.5}$, PM_{10}, TSP, and CO)

Monitoring the PM levels on the production floor was achieved with air particulate mass monitor (Model GT-331), from Met-One Instruments, Grants Pass, OR, USA. The device is a battery operated and completely portable unit capable of measuring five ranges of particulate: PM_1, $PM_{2.5}$, PM_7, PM_{10}, and TSP with a concentration range of 0–1 mg/m^{-3} and resolution of 0.1 μg/m^{-3}. It employs the light scattering principle to measure the individual particles that pass through the laser optical system (no correction factor is required). Information from the manufacturer indicates that during factory calibration of the GT-331 monitor, its mass concentration reading has been checked against a beta attenuation monitor (BAM), which is a reference standard method of measuring mass concentration, thus, no correction of the output concentration is needed (Fakinle et al., 2013). The device's liquid crystal display allows real-time viewing of the measured concentrations. At the selected locations in each section of the recycling facility, the sampler was positioned at a height of 1.4 m to represent air at the breathing height. For measurement of CO, a ToxiRae II single gas monitor from RAE Systems, San Jose, CA, USA, was used. 24- and 8-hr measurements were adopted for PM and CO, respectively. All measurements were taken at the same locations for three consecutive days.

2.2 | Toxicity potential (TP)

The TP of the pollutants were determined using Equation (1)

$$TP = \frac{P_{\text{concentration}}}{S_{\text{limit}}} \tag{1}$$

where $P_{\text{concentration}}$ = concentration of pollutants (μg/m^3) and S_{limit} = statutory limit set for pollutants concentrations.

The TP of TSP was based on the recommended limits for TSP as set by Nigeria's FMENV, the World Bank, and the World Health Organization (WHO) (FMENV, 1991; World Bank, 1998; WHO, 1979), while the TP of $PM_{2.5,}$ PM_{10}, and CO were based on limits recommended by the US EPA (Han & Naeher, 2006; US EPA, 2006). TPs calculated above 1.0 indicate unhealthy conditions.

3 | RESULTS AND DISCUSSION

3.1 | Concentrations of air pollutants

The 24-hr averaging period concentrations of $PM_{2.5}$, PM_{10}, and TSP within the facility ranged from 8.3 to 50.4 μg/m^3 (see the table in **Exhibit 1**), from 12.0 to 151.3 μg/m^3 (see the table in **Exhibit 2**), and from 30.0 to 285.0 μg/m^3 (see the table in **Exhibit 3**), respectively, while the maximum 8-hr CO within the plant was 20.5 ppm, as shown in the table in **Exhibit 4**. Based on the observed concentrations of pollutants, certain locations around the furnace appeared to be of interest. The 35 μg/m^3 limit for PM $_{2.5}$ for an average time of 24 hr set by US EPA

EXHIBIT 4 Measured 8-hr concentrations of CO

Factory section	Concentration of CO (ppm) Day 1	Day 2	Day 3	Mean
Scrap yard	5.6	9.2	8.9	7.9
Furnace	19.7	20.3	21.5	20.5
Billet	7.1	6.9	8.7	7.6
*Rh-oven	9.9	8.2	7.3	8.5
Rolling	—	—	—	—
Loading	3.5	4.9	5.2	4.5

*Re-heating oven.

EXHIBIT 5 Computed TPs of TSP in various sections of the factory

Section	TSP FMENV	TSP WHO Lower	TSP WHO Upper	TSP World Bank	$PM_{2.5}$	PM_{10}	CO
Scrap yard	0.23	0.39	0.25	0.71	0.50	0.25	0.88
Furnace	1.14	1.90	1.24	3.56	1.44	1.01	2.28
Billet	0.18	0.29	0.19	0.55	0.34	0.21	0.84
*Rh-oven	0.15	0.25	0.17	0.48	0.46	0.19	0.94
Rolling	0.21	0.35	0.27	0.65	0.28	0.11	—
Loading	0.12	0.20	0.13	0.38	0.24	0.08	0.50

*Re-heating oven.

was exceeded at sampling locations around the furnace. Similarly, the 150 $\mu g/m^3$ limit for PM_{10} and the 8-hr limit for CO were also exceeded near the furnace.

The 24-hr averaging period for TSP limits recommended by the Nigeria's FMENV, the World Bank, and the WHO, were exceeded around the furnace. The concentrations of these pollutants were found to be higher near the furnace than at any other section of the factory's production floor. The high concentration of particulates observed near the furnace was probably due to combustion process involving diesel fuel, which has been known to emit considerable amounts of particulates (Collings & Graskow, 2000). The PM could also be due to emissions from junk metals under combustion.

Observations made by the researchers during the field study indicated that the majority of the factory workers did not use personal protective devices. The factory runs two shifts over 24 hr, indicating that factory workers whose work schedules place them around the furnace are exposed to these pollutants for a minimum of 12 hr a day. This could lead to both short- and long-term health-related diseases.

3.2 | Toxicity potential (TP)

As summarized in the table in **Exhibit 5**, the computed TP of TSP at the factory's monitoring points ranged between 0.12 and 1.14 using Nigeria's 24-hr averaging period national particulate limit, but when the lower and upper limits set by the WHO were used, the TP ranges were 0.20–1.90 and 0.13–1.24, respectively. The World Bank limit gave TPs ranging between 0.38 and 3.56. Considering all of the factory sections where pollutants monitoring were performed, and all of the recommended TSP limits, the maximum TP of TSP around the scrap yard, furnace, billet, re-heating oven, rolling, and loading sections ranged from 0.23 to 0.71; 1.14 to 3.56; 0.18 to 0.55; 0.15 to 0.48; 0.21 to 0.65; and 0.12 to 0.38, respectively.

The TPs of $PM_{2.5}$, PM_{10}, and CO were also greater than 1.0 around the furnace. The areas near the furnace had the greatest TP values in the factory, while the loading bay had the lowest values. As stated earlier, TP above 1.0 is an indication of unhealthy air, hence locations near the furnace, where TPs were above 1.0, are a cause for concern.

4 | CONCLUSION AND RECOMMENDATION

The 24-hr averaging period concentrations of $PM_{2.5}$, PM_{10}, and TSP, as well as the 8-hr CO concentrations were monitored at major sections on the production floor of a scrap metal recycling factory. These monitored concentrations were combined with their recommended limits to establish their toxicity potentials. Results from the study revealed that for the 24-hr averaging periods for $PM_{2.5}$, PM_{10}, and TSP, and the 8-hr period for CO, the measured concentrations at all the monitoring points were within recommended limits, except at the locations near the furnace. The TPs of the investigated pollutants were greater than 1.0 only around the furnace; an indication of poor air condition. Workers whose work schedules place them near the furnace are exposed to this pollution level for a minimum of 12 hr a day. This could pose the risk of both short- and long-term health-related diseases for such workers. One approach to reduce exposure includes provision and enforcement of the use of protective devices. Another approach would be to increase the number of shifts from two to three, thus reducing the daily exposure duration. A third approach is to improve ventilation around the furnace to reduce pollutant concentrations.

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