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Environmental Monitoring of Ambient Outdoor, Indoor Air Quality Pollutants, PM 10 and PM 2.5 Conducted to Evaluate Its Impact Analysis and Quantification in Industrial Area of Dammam, KSA

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Abstract

The core objective of this study is to conduct precise and real-time monitoring of the industrial area Dammam located in the Kingdom of Saudi Arabia (KSA) which consists of a number of various chemicals, minerals and petrochemicals along with administrative blocks. The objective of this study is to monitor possible outdoor and indoor air pollutant in the industry working environment. This study shall help us to enable decision to be made on appropriate control measures as may be required to protect the health of employee and occupant who may be exposed to air contamination at workplace. Air pollution monitoring in ambient air environment finding shall be compared with national ambient air quality environmental standard while parameters monitoring in indoor air environment is compared with international standards such as occupational health and safety administration (OSHA), National institute for occupational safety and health (NIOSH) and Australian national health and medical research council (NHMRC). This environment review study for ensuring industry regulatory compliance for the facility and general authority of meteorology and environmental protection (GAMEP) previously known as presidency of meteorology environment (PME). This study shall be comprehensive in nature and cover two major types of monitoring and assessment such as ambient air quality monitoring and indoor air quality monitoring.

Keywords

Environmental Analysis, Presidency of Meteorology Environment, General

Authority of Meteorology and Environmental Protection, Occupational Health and Safety Administration, National Institute for Occupational Safety and Health

1. Introduction

This work aims to conduct and identify level of ambient and indoor air quality pollutants targeted to the 3rd industrial area of Dammam, KSA. This study and analysis help us to understand human working atmosphere in the industrial area. We have targeted critical and non-critical parameters to provide safe and conducive work atmosphere. Various environmental regulatory agencies ensure compliance of standard. Air pollution is an important public health problem in developed and developing nations (Issever et al., 2005). Worldwide, there are more than 2.7 million deaths due to air pollution (Nguyen & Kim, 2006a, 2006b). Sources of air pollution include road traffic emissions, industrial emissions and domestic heating, or secondary formation pollutants (Marc-Andre et al., 2007; Kassomenos et al., 2006; Ogrin, 2007, Potoglou & Kanaroglou, 2005) and (Charles et al., 2005). Common air pollutants that draw intense concerns include particulate matter (PM), ozone (O_3), carbon monoxide (CO), sulfur dioxide (SO_2), nitrogen dioxide (NO_2), and volatile organic compounds (VOCs) (Muir et al., 2006).

PM is a mixture of constituents that are formed by a large range of mechanisms associated with both natural and anthropogenic origins (Guerra et al., 1995). Exposure to high concentrations of PM increases the risk of lung cancer, respiratory diseases, arteriosclerosis, as well as changes in heart rate variability (Alves et al., 2000). In addition, aerosol particles have an impact on the environment in areas such as visibility and staining of buildings (de Kok et al., 2006; Sun et al., 2004; Virtanen et al., 2006).

CO is a flammable and poisonous gas emitted from incomplete combustion of carbonaceous material. Once absorbed, CO diffuses to plasma, passes across the red blood cell membrane, and finally enters the red blood cell cytoplasm where it binds to hemoglobin (Hb) forming carboxyhemoglobin (COHb). The affinity of Hb for CO is 210 - 300 times greater than for oxygen, and Hb is thus incapable of combining with oxygen (Fang et al., 2006; Menut, 2003).

NO_2 is released into the atmosphere from natural and man-made sources (e.g., burning of fossil fuels, construction, and mining). It is considered one of the main traffic-related air pollutants. A great number of studies have assessed the air pollution effects of nitrogen oxides (NO_x) on human health. For instance, a cohort study reported significant increases in cardiopulmonary mortality for those living near major road areas in the Netherlands (Bono et al., 2007). NO_x together with VOCs are responsible for the formation of photochemical smog and ground-level O_3 in the presence of sunlight (Muir et al., 2006).

SO_2 is emitted into the atmosphere mainly from anthropogenic sources such as the combustion of sulfur-containing fossil fuels (e.g., coal, oil, and natural gas). Peak levels of SO_2 in the air can cause temporary breathing difficulty for people with asthma who are active outdoors. Longer-term exposures to high levels of SO_2 and particles cause respiratory illness and aggravate existing heart disease. SO_2 and NO_x in the atmosphere are the major contributors to acidification. Acid rain damages forests and crops, changes the makeup of soil, and makes lakes and streams acidic and unsuitable for fish. VOCs are those organic compounds that have boiling points roughly in the range of 50˚C - 250˚C (Shaw et al., 2005). Outdoors VOC concentrations are affected by season and temperature, proximity to emission sources such as industry, traffic and gas stations (Jia et al., 2008; Kwon et al., 2006; Kingdom of Saudi Arabia, Royal Commission for Jubail and Yanbu, 2010). Indoors VOCs concentrations are affected by outdoor levels due to the exchange of indoor and outdoor air, and by the numerous sources present indoors (Sapkota et al., 2006; Batterman et al., 2007; Charles et al., 2007; Tipton & Dzombak, 2005).

The VOCs enter the atmosphere at room temperature and may cause headaches, dizziness, nausea and irritation of mucous membranes (Teixeira et al., 2009; Nathanson, 1995; U.S. Environmental Protection Agency, 2001; Sivertsen, 1997).

The air pollution problem inside or over the industrial area has different sources, including the plant operation and related activities. The general objective of this study is the assessment of air quality level inside the industrial area. This study will be considered as a benchmark of the environmental database for all industrial areas in the eastern province of the Kingdom of Saudi Arabia.

2. Data and Research Methods

2.1. Research Area Overview and Data

3rd Industrial City is located at 150 kilometers from city of Dammam which is a coastal city located in the Eastern Province of the Kingdom of Saudi Arabia (**Figure 1**). The geographic position system (GPS) coordinate of each corner of project site NW: 25˚55'8.25"N, 49˚57'32.26"E; NE: 25˚55'8.66"N, 49˚57'35.63"E; SE: 25˚55'3.22"N, 49˚57'35.45"E; and SW: 25˚55'3.17"N, 49˚57'32.21"E. During the present study, levels of the ambient air pollution were studied at two different locations. Location were the main gate and inside the premises. Ambient outdoor and indoor air quality pollutants include temperature, relative humidity, nitrogen dioxide, sulphur dioxide, hydrogen sulphide, ammonia, carbon monoxide, nitrogen oxide, ozone, carbon dioxide and total volatile organic compounds, particulate matter PM 10 and PM 2.5) were monitored at the boundary and inside of the facility. All reported values are in compliance with national ambient quality standards at all locations.

2.2. Monitoring Methods

A valid certified calibrated portable YES Plus LGA air quality monitor and AEROCET 531, particle mass monito (Class 1 laser product complies with IEC

60825-1 Ed.1.1, EN60825-1 W/A11 and US 21 CFR 1040.10) were used to monitor ambient (outdoor) and indoor air quality. Air quality parameters monitored for ambient and indoor environment is shown in Table 1. Each location was monitored for fifteen (15) minutes. These monitoring were conducted at a height of 1.5 m above ground level. The height is approximately equal to the employee's breathing zone so that the concentrations measured will accurately reflect the concentration that is inhaled.

Air quality monitoring was conducted on December 14, 2019. Air quality monitoring data recorded at the various location of plant and various area mentioned in Table 2 of the facility is shown in Table 3.

2.3. Temperature and Relative Humidity

The ambient average temperature and relative humidity vary from 24˚C - 27.1˚C and 18.4% - 26.2% during the day time. Figure 2 and Figure 3 graphically illustrates the temperature and relative humidity data in respectively. The temperature and humidity potential to increase in the summer season due to desert natural environment.

Figure 1. Facility location in industrial city (local context).

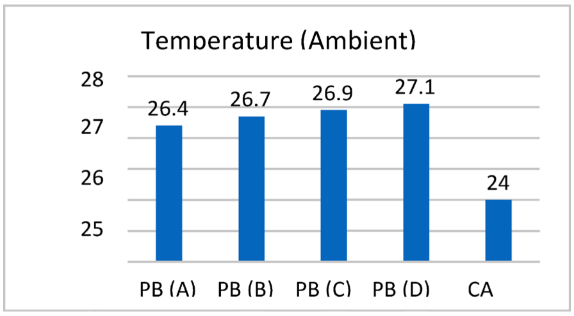

Figure 2. Ambient temperature data.

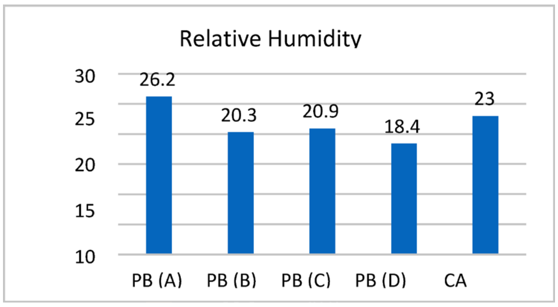

Figure 3. Ambient relative humidity data.

Table 1. Ambient and indoor air quality parameters.

Ambient air quality parameter	Indoor air quality parameter
• Temperature	• Temperature
• Relative Humidity	• Relative Humidity
• Carbon monoxide (CO)	• Carbon dioxide (CO_2)
• Nitrogen dioxide (NO_2)	• Carbon monoxide (CO)
• Ozone (O_3)	• Nitrogen dioxide (NO_2)
• Hydrogen sulphide (H_2S)	• Nitric oxide (NO)
• Sulphur dioxide (SO_2)	• Ozone (O_3)
• Particulate Matter (PM 10)	• Ammonia (NH_3)
• Particulate Matter (PM 2.5)	• Hydrogen sulphide (H_2S)
	• Sulphur dioxide (SO_2)
	• Total Volatile organic compounds (TVOCs)
	• Particulate Matter (PM 10)
	• Particulate Matter (PM 2.5)
	• Total Suspended Particulate

Table 2. Ambient and indoor monitoring locations.

Ambient Monitoring Locations	Indoor Monitoring location
• Plant boundary A—PB (A)	• Laboratory—Lab
• Plant boundary B—PB (B)	• Production Area 1—PA 1
• Plant boundary C—PB (C)	• Production Area 2—PA 2
• Plant boundary D—PB (D)	• Warehouse 1—WH 1
• Crushing Area (CA)	• Warehouse 2—WH 2

Table 3. Ambient air quality monitoring data.

Location	Temp. ˚C	RH %	NO_2 ppm	SO_2 ppm	H_2S ppm	CO ppm	O_3 ppm	PM 2.5 μg/m^3	PM 10 μg/m^3
Plant Boundary (PB-A)	26.4	26.2	0.0	0.5	0.04	0.9	0.06	29.2	159.3
Plant Boundary (PB-B)	26.7	20.3	0.0	0.0	0.03	1.7	0.09	27.8	156.7
Plant Boundary (PA-C)	26.9	20.9	0.0	0.0	0.04	2.0	0.09	21.7	103.3
Plant Boundary (PA-D)	27.1	18.4	0.0	0.1	0.04	2.1	0.08	18.3	89.2
Crushing Area (CA)	24.0	23.0	0.0	0.0	0.03	1.0	0.08	25.2	157.9

2.4. Ambient Air Pollutant

Reported data of sulphur dioxide (SO_2), carbon monoxide (CO), ozone (O_3), and hydrogen sulfide (H_2S) and particulate matter (PM 10 and PM 2.5) are shown in Figures 4-9 respectively. All values are in compliance with national ambient quality standards at all locations. Figures 7-9 depict PM 2.5, 10 and hydrogen sulphide.

3. Indoor Air Quality Environment

Air quality parameters include temperature, relative humidity, nitrogen dioxide, sulphur dioxide, hydrogen sulphide, ammonia, carbon monoxide, nitrogen oxide, ozone, carbon dioxide and total volatile organic compounds, particulate matter PM 10, particulate matter PM 2.5 and total suspended particulate (TSP). Indoor air quality recorded at the facility is shown in Table 4.

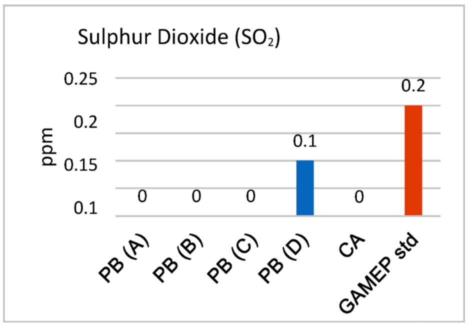

Figure 4. Ambient sulfur dioxide data.

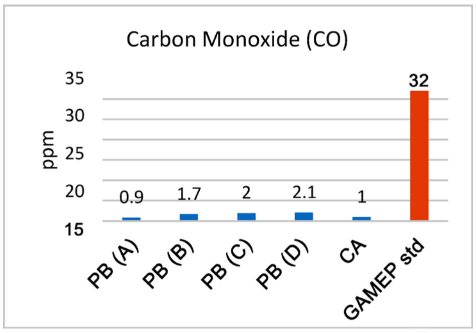

Figure 5. Ambient carbon monoxide data.

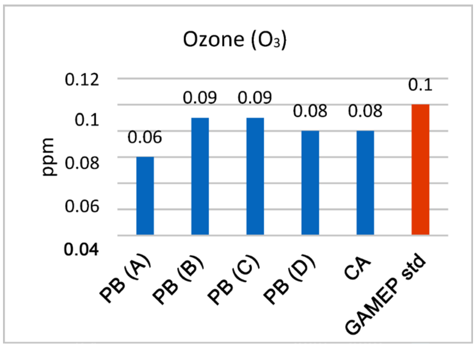

Figure 6. Ambient ozone data.

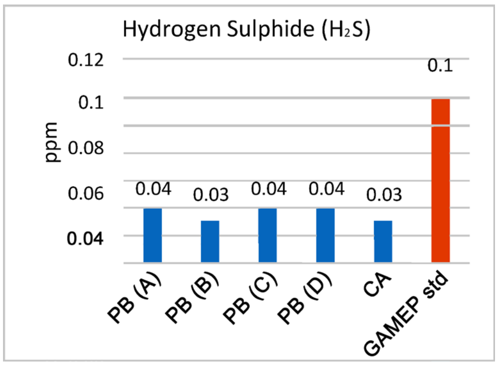

Figure 7. Ambient hydrogen sulphide data.

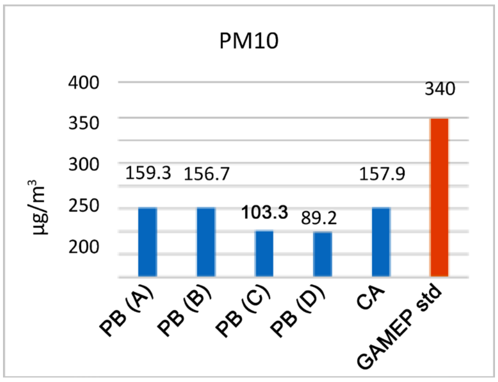

Figure 8. Ambient PM 10 data.

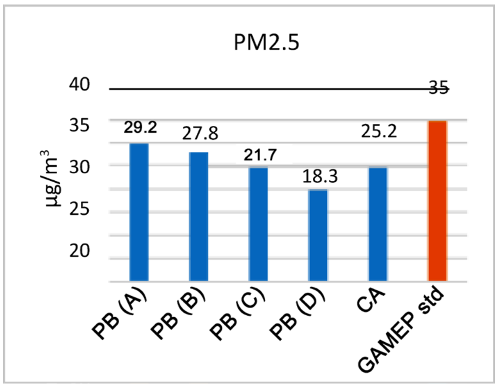

Figure 9. Ambient PM 2.5 data.

Table 4. Indoor air quality monitoring data.

Location	Temp. ˚C	RH %	NO_2 ppm	SO_2 ppm	H_2S ppm	NH_3 ppm	CO ppm	NO ppm	O_3 ppm	CO_2 ppm	VOC mg/m³	PM 2.5 µg/m³	PM 10 µg/m³	TSP µg/m³
Lab	22.1	31.3	0.0	0.1	0.4	0.0	2.1	0.7	0.0	406.3	234.0	30.2	67.3	73.8
PA 1	23.7	23.0	0.0	0.6	0.3	0.0	2.5	0.3	0.3	361.4	310.0	118.3	195.2	957.8
PA 2	23.3	24.0	0.0	0.0	0.3	0.0	0.9	0.3	0.7	338.5	334.0	70.5	130.4	810.2
WH 1	23.4	23.2	0.0	0.0	0.3	1.0	1.0	0.4	0.6	338.8	189.0	61.5	145.3	557.5
WH 2	23.4	24.0	0.0	0.0	0.3	1.0	1.0	0.4	0.4	367.7	264.0	50.8	105.7	390.9

3.1. Temperature and Relative Humidity

Temperature and relative humidity are often referred to as comfort parameters and contribute to the thermal comfort for indoor working personnel. There are no "ideal" humidity and temperature standards suitable for all building occupants or indoor work areas therefore different organizations have varying standards. The average temperature and relative humidity data monitored at each location is compared with NIOSH standards.

Figure 10 and Figure 11 graphically illustrates the temperature and relative humidity data with NIOSH lower and upper limit standard. Temperature and relative humidity were in compliance with NIOSH standards. The monitoring was undertaken in the winter season but there is potential to increase temperature and humidity in the summer season.

3.2. Indoor Air Pollutants

Reported data of carbon monoxide (CO), sulphur dioxide (SO_2), hydrogen sulfide (H_2S), nitric oxide (NO), ozone (O_3), total volatile organic compounds (TVOCs) and carbon dioxide (CO_2), particulate matter (PM 10), particulate matter (PM 2.5) and total suspended particulates with standards are shown in Figures 12-21 respectively. Figure 19 and Figure 20 represent the PM 2.5 and PM 10 data was reported above IDPH (65 μg/m^3 and 150 μg/m^3) standards.

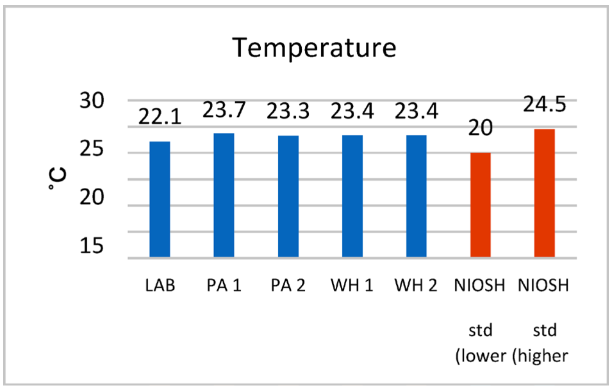

Figure 10. Indoor temperature data.

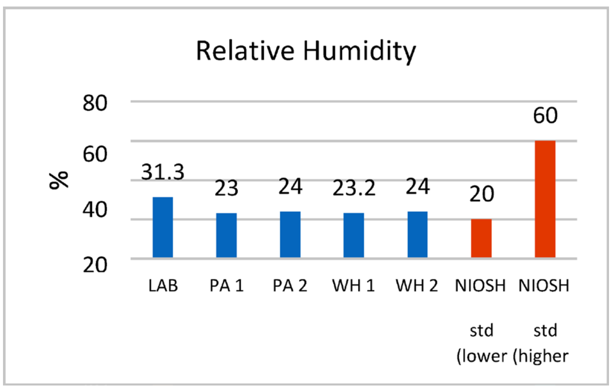

Figure 11. Indoor relative humidity.

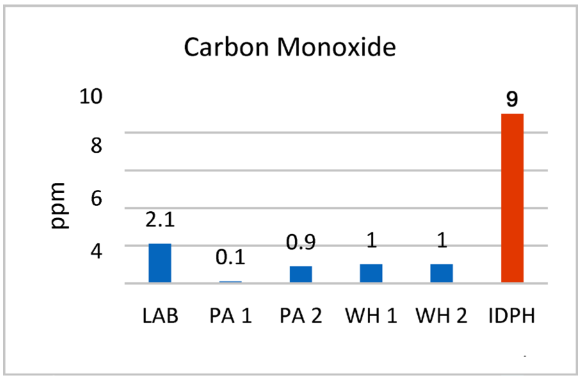

Figure 12. Indoor carbon monoxide data.

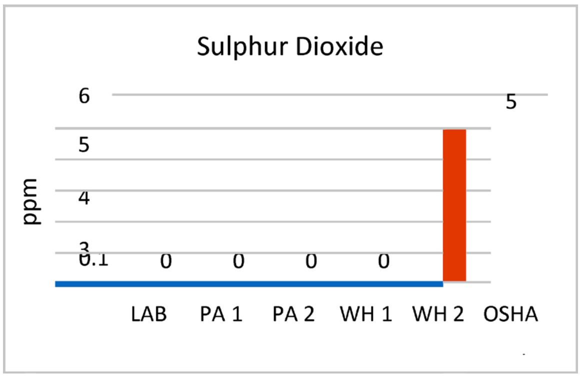

Figure 13. Indoor sulfur dioxide data.

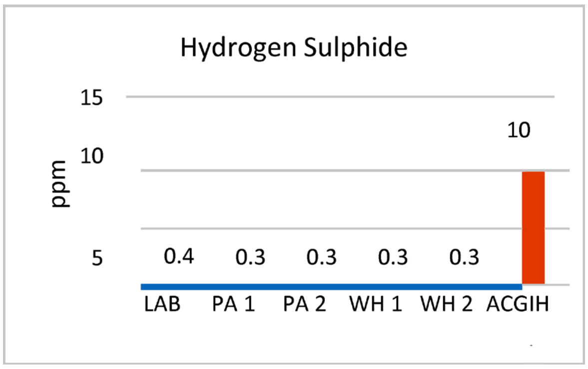

Figure 14. Indoor hydrogen sulfide data.

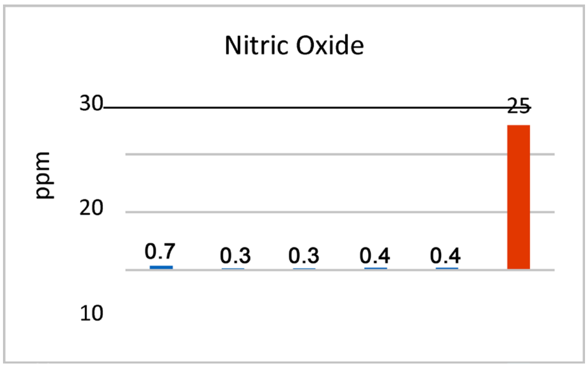

Figure 15. Indoor nitric oxide data.

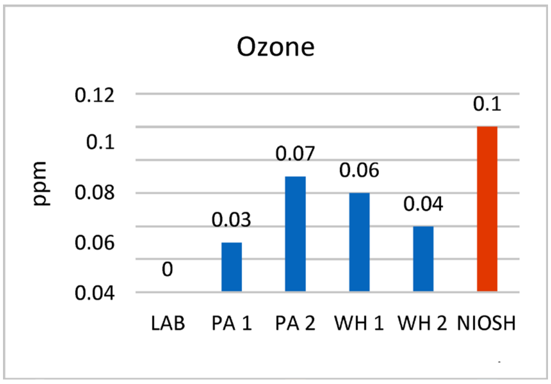

Figure 16. Indoor ozone data.

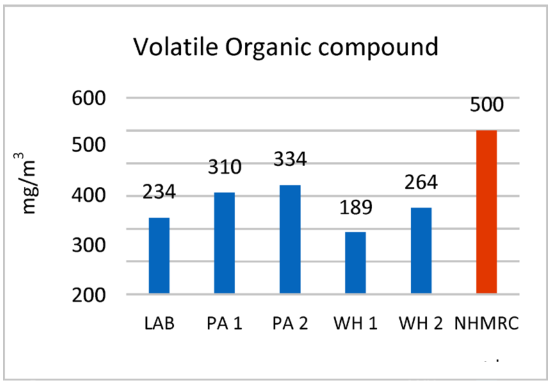

Figure 17. Indoor VOC data.

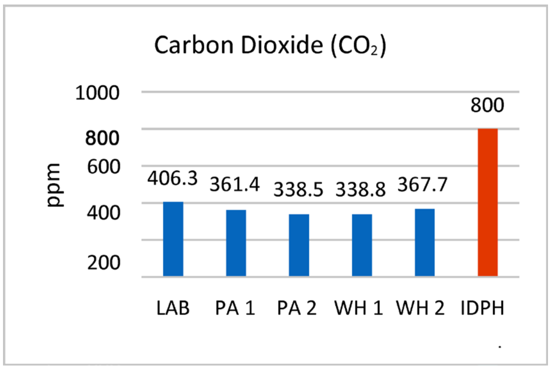

Figure 18. Indoor carbon dioxide data.

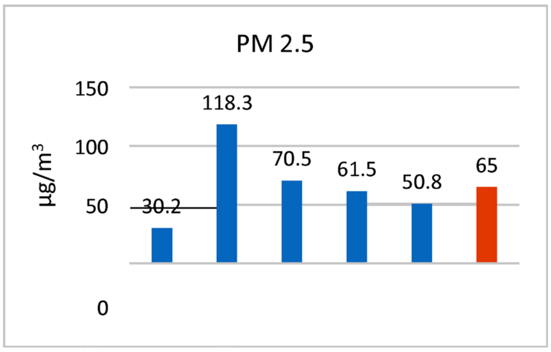

Figure 19. Indoor PM 2.5 data.

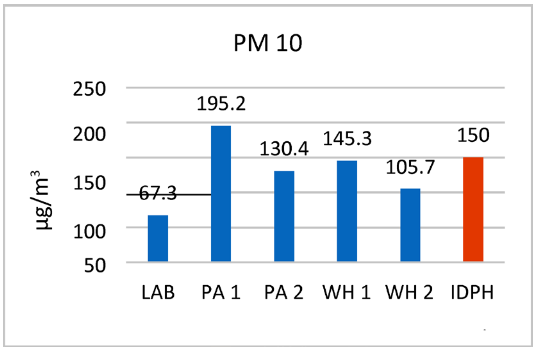

Figure 20. Indoor PM 10 data.

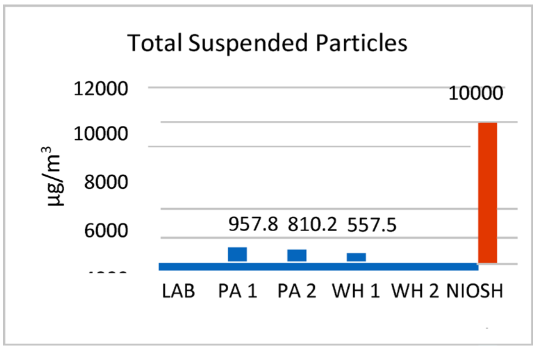

Figure 21. Indoor total suspended particles data.

Table 5. Ambient air quality standards.

Parameter	Time-weighted averageμg/Nm³ (ppm)	Averaging time	Number of allowable exceedances
Carbon Monoxide	10,000 (8.1)	8 hours	None
	40,000 (32)	1 hour	
Lead	0.5 (0.00005)	Annual	N/A
Nitrogen Dioxide	660 (0.35)	1 hour	2 times per 30 days
	100 (0.05)	Annual	N/A
Sulphur Dioxide	730 (0.28)	1 hour	2 times per annum
	365 (0.14)	24 hours	1 time per annum
	80 (0.03)	Annual	N/A
Benzene	5 (0.0015)	Annual	N/A
Particulate Matter (PM 10)	340 (variable)	24 hours	24 times per annum[b]
	80 (variable)	Annual	N/A
Particulate Matter (PM 2.5)	35	24 hours	24 times per annum[c]
	15	Annual	N/A
Ozone	235 (0.12)	1 hour	2 times per 30 days
	157 (0.08)	8 hours	2 times per 7 days
Hydrogen Sulphide	150 (0.1)	24 hours	10 times per annum
	40 (0.03)	Annual	N/A

[a]Violations will only be reportable where validated data is available for 98% of measurements; [b]The average 90th Percentile 24-hour concentration must not exceed 340 μg/Nm³; [c]The average 90th Percentile 24-hour concentration must not exceed 35 μg/Nm³.

Table 6. Indoor air quality standards.

Parameter	IDPH	NHMRC	NIOSH	OSHA	ACGIH
Relative humidity	20% - 60%	-	20% - 60%	20% - 60%	-
Temperature (˚C)	20 - 24 (winter) 22.8 - 26.1 (summer)	20 - 26	20 - 24.5	20 - 26	- - - -
Carbon dioxide	1000 ppm 800 ppm preferred	-	1000	5000 ppm	5000 ppm
Carbon monoxide	9 ppm	9 ppm (8 hours)	35 ppm	50 ppm	25 ppm
Volatile organic compounds	-	500 µg/m^3 (0.218 ppm) (1 hour)	-		
Sulfur dioxide	-	200 ppb (1 hour)	2 ppm (5 ppm/15 minute)	5 ppm (8 hr)	5 ppm (15 min)
Hydrogen sulfide	0.01 ppm	-	-	20 ppm	10 ppm
Ozone	0.08 ppm		0.1 ppm	0.1 ppm	0.05 ppm
Nitrogen dioxide	0.05 ppm (24 hours average)	-	1 ppm/15 min	5 ppm (8 hr)	3 ppm 5 ppm (15 min)
Nitric Oxide	-	-	-	25 ppm	-
Ammonia	-	-	-	50 ppm	-
PM 10	150 µg/m^3	-	-	-	-
PM 2.5	65 µg/m^3	5000 µg/m^3	3000 µg/m^3	-	-
TSP	-	15,000 µg/m^3	10,000 µg/m^3	-	-

All values are in compliance with OSHA/NIOSH/ACGIH/IDPH/NHMRC standards where applicable except particulate matter PM 10 and PM 2.5 at production area.

3.3. Ambient Air Quality Standard

Ambient air quality standards (AAQS) of kingdom of Saudi Arabia are outlined in Table 5. There are different agencies globally that develops Indoor air quality standards. The indoor air quality standards from international agencies from the National Institute of Occupational Health and Safety (NIOSH), Occupational Safety and Health Administration (OSHA), American Conference of Governmental Industrial Hygienists (ACGIH), Illinois Department of Public Health (IDPH), Australian National Health and Medical Research Council (NHMRC) are represented in Table 6. These standards will be used to evaluate monitoring data where applicable.

4. Conclusion

The findings of the ambient air quality monitoring study show that the air quality parameters are within the acceptable limit of national ambient air quality standards. The findings of the indoor air quality monitoring study show that the air quality parameters are within the acceptable limit of working environment except for particulate matter, PM 10 and PM 2.5 at production area.

We recommend wearing appropriate personal protective equipment (PPE) and a nose mask must be mandatory at production areas.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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