

Pollution of PM₁₀ in an underground enclosed loading dock in Malaysia

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Abstract: The enclosed nature of underground loading docks results in accumulation of motor vehicles emissions. Thus, concentration of numerous harmful air pollutants including PM₁₀ particles can increase and reach dangerous levels. This paper aims to study short-term and long-term exposure of PM₁₀ particles inside an underground loading dock located in Malaysia. In addition, the correlation with indoor temperature, relative humidity and vehicles flow will be measured. The concentrations of PM₁₀ were measured for three consecutive weeks using the real-time air quality monitoring instrument AQM60. Series of statistical tests and multiple linear regression analysis were applied on the data using SPSS software and MATLAB R2013a. The results illustrated that PM₁₀ daily average concentration was in compliance with the Malaysian guideline of 150 µg/m³. Actually, 95 % of instantaneous PM₁₀ concentration readings were below 75 µg/m³. In addition, significant correlation were found between PM₁₀ concentration and indoor temperature, relative humidity and the previous concentration. The multiple *R* and *R*² were 0.91 and 0.83, respectively. PM₁₀ concentration was also correlated with motor vehicles flow. In conclusion, health effects of long-term exposure to small repetitive doses of air pollutant inside underground facilities should be studied and appropriate control measures need to be implemented.

1. Introduction

Stable economic development and increase in human population contribute in making surface land scarcer and much expensive especially in highly populated cities [1]. Hence, most governments try to utilize their land resources to maximum extent. Consequently, construction of many facilities including loading docks has been shifted underground [2]. The main source of air pollution inside such underground micro-environments is emissions of motor vehicles [3]. Motor vehicles basically emit particulate matter (PM), carbon monoxide (CO), carbon dioxide (CO₂), oxides of nitrogen (NO_x), sulfur dioxide (SO₂) and hydrocarbons (HC) [1, 4]. The confined environment of underground loading docks and the restricted contact with ambient air, result in quick accumulation of air pollutants that build up and cause poor indoor air quality. Without the installation of proper mitigation measures like

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mechanical ventilation systems, underground loading docks can become a dangerous working environment, as both of employees and users will be exposed to high concentrations of harmful gases [2]. PM₁₀ particles basically consist of complex suspended particles in the air with different composition and size smaller than 10 µm. These particles enter the respiratory tract, which ultimately causes serious respiratory diseases [5].

Presence of PM₁₀ pollution inside enclosed micro-environment has been confirmed by different studies. For example, Li, & Xiang [1] reported that the 14-hour average PM₁₀ concentration inside an underground enclosed car park, was 56% higher than the Chinese indoor PM₁₀ standard of 150 µg/m³. Similarly, Johansson and Johansson [6] observed high PM₁₀ concentration at an underground station in central Stockholm. In the same context, Raut, et al. [7] stated that PM₁₀ average concentration in a confined rail station was 5-30 times higher than those measured on of the busiest streets of Paris.

Previous studies showed that the indoor air quality of underground loading docks has not been explored much yet. Underground loading dock has a unique environment in term of number of people and the time duration they spend inside. Unlike other underground facilities such as car parks and bus station, the workers spent up to 8 hours a day in underground loading docks. Even more, the number of workers is higher than those in other underground spaces. PM₁₀ is a very common motor vehicle pollutant and has been linked with respiratory and cardiovascular morbidity [8, 9]. Therefore, this paper is focusing on PM₁₀ pollution inside an underground enclosed loading dock.

2. Material and methods

2.1. Sampling area

The study area was selected inside an underground loading dock area located in Kuala Lumpur (KL), which is the capital and the most populous city in Malaysia with more than 1.6 million people [10]. The loading dock is located in the Kuala Lumpur City Center (KLCC) and has the coordinates of 3° 09' 28.3" N 101° 42' 41.7" E. It is heavily utilized because it serves many famous and attractive shopping malls and restaurants, commercial buildings and governmental agencies. The observations showed vehicles rate of one per two minutes during working hours from 8:00 AM to 5:00 PM except break time (1:00 PM to 2:00 PM). Moreover, the loading dock is used for disposing of garbage during night hours. The loading dock is equipped with traditional duct ventilation system that operates only during working hours at a rate of 6 ACH.

2.2. Sampling instrument

Air Quality Monitoring (AQM60) Environmental Station was used for measuring PM₁₀ concentration levels inside the loading dock though a particle monitor (Nephelometer) [11]. Nephelometer accuracy was at ± 2 µg/m³, with range of 0 - 2000 µg/m³. AQM60 was installed near the administrative office where workers who spend 8 hours every day inside, could be under the risk of exposure to air pollution from motor vehicle. Measurement of PM₁₀ concentrations started on Monday December 1, 2014 and lasted for two weeks. AQM60 was adjusted to measure PM₁₀ concentration levels after every two minutes. RF modem was used to retrieve the data from the AQM60 unit.

2.3. Data analysis:

Series of descriptive statistical tests have been applied on the collected data using Statistical Package for the Social Sciences (SPSS) software and Microsoft Excel 2013. Descriptive statistical tests include number of valid and missing values, minimum and maximum values, percentiles, average, median and mode. These tests would help organize, summarize and interpret the compiled data. In addition, MATLAB R2013a was used for correlating PM₁₀ concentrations with the previous concentration, indoor temperature, relative humidity and traffic flow using multiple liner regression (MLR).

3. Results and discussion

Throughout twenty one days of study, 14,847 valid readings of PM₁₀ concentrations were recorded, whereas, damaged and missed vales were approximately 2 % out of the total. The corrupted values irregularly happened and they remain in compliance with the 5 % accuracy of AQM60 [11]. Hence, they were being excluded following the Listwise deletion technique [12].

3.1. Short-Term exposure of PM₁₀ concentrations

Table 1 gives the summary of PM₁₀ daily average concentrations that have been recorded inside the loading dock during the three weeks of measurements.

Table 1. Daily average PM₁₀ concentration inside the loading dock

Parameter	Range	Average
PM ₁₀ concentration ($\mu\text{g}/\text{m}^3$)	24.82 – 51.05	35.59 \pm 7.27

As can be obviously seen in Table 1, the 24-hour average PM₁₀ concentration level inside the loading dock fluctuated between 24.82 $\mu\text{g}/\text{m}^3$ and 51.05 $\mu\text{g}/\text{m}^3$, with an average of 35.59 \pm 7.27 $\mu\text{g}/\text{m}^3$. Due to the lack of specific air quality guidelines for underground confined micro-environments in Malaysia, the Industry Code of Practice on Indoor Air Quality (ICOP-IAQ) was adapted [13]. PM₁₀ concentration levels inside the loading dock was remarkably below the daily averaged PM₁₀ guidelines of 150 $\mu\text{g}/\text{m}^3$. Eventhough the World Health Organization (WHO) has a tighter PM₁₀ standard of 50 $\mu\text{g}/\text{m}^3$ [14], PM₁₀ average concentration is still within the acceptable limit (Figure 1). However, the highest average concentration was slightly higher than the standard with only 1.05 $\mu\text{g}/\text{m}^3$. The WHO guidelines was violated twice during the three weeks of study as the second and the third highest daily averaged PM₁₀ concentration were 50.94 $\mu\text{g}/\text{m}^3$ and 46.47 $\mu\text{g}/\text{m}^3$, respectively. The first and the second highest PM₁₀ average concentrations were recorded on Sundays, the 7th and the 21th of December due to operating the ventilation system at lower rate than in other days because of the low traffic during weekends. In addition, the cleaning process during weekends cause dust to be resuspended again. The differences in PM₁₀ concentrations are deeply linked with traffic flow.

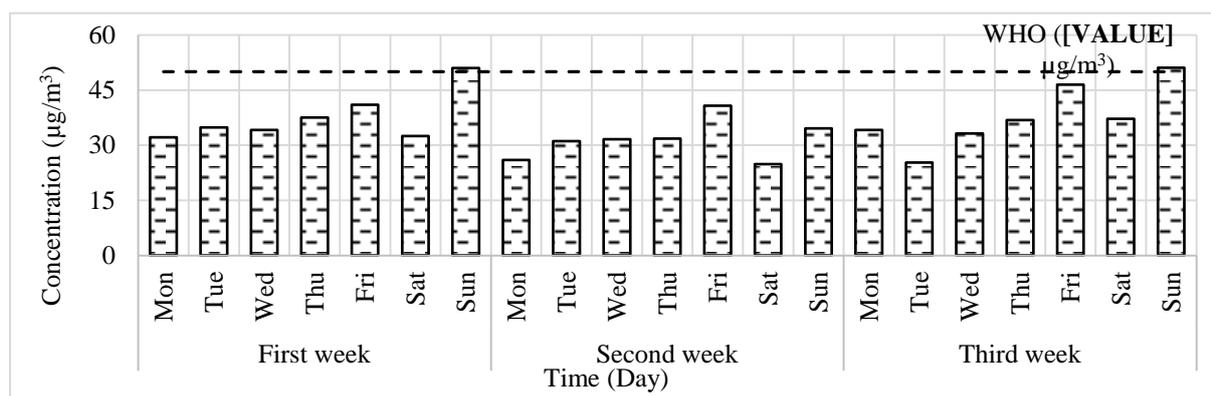


Figure 1: Daily average PM₁₀ Concentration level

3.2. Long-Term exposure of PM₁₀ concentrations

The instantaneous PM₁₀ readings has been studied in order to locate the long-term exposure of PM₁₀ concentrations. Valid PM₁₀ concentration readings have been summarized using the boxplot diagram. Figure 2 provides information on the instantaneous PM₁₀ concentration readings inside the loading dock during the study period of twenty one days. The minimum and maximum values of PM₁₀ concentrations were 0.09 $\mu\text{g}/\text{m}^3$ and 656.51 $\mu\text{g}/\text{m}^3$, respectively. This

depicts that PM_{10} concentration has a wide range (Difference between the maximum and the minimum values) of $656.42 \mu\text{g}/\text{m}^3$. Similarly, there are other researchers who have reported extremely high PM_{10} concentrations inside underground facilities [1, 6].

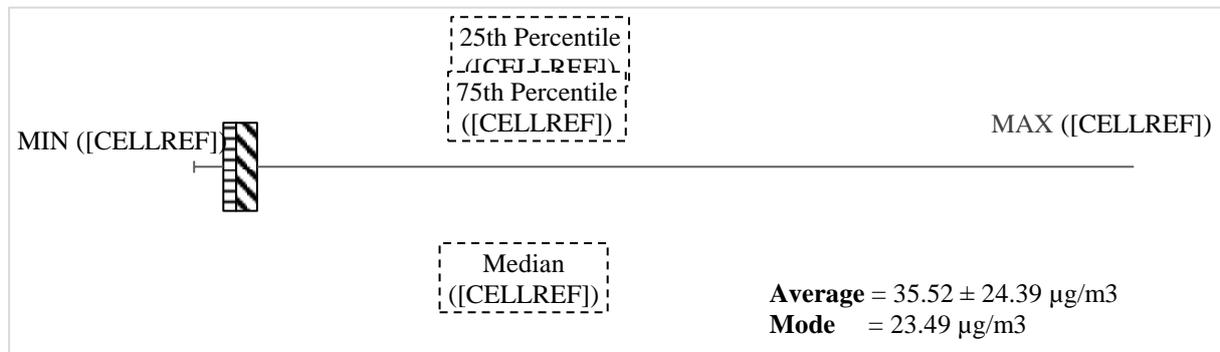


Figure 2: Boxplot for PM_{10} concentrations of the three weeks

The average, median and the mode of PM_{10} concentration levels were $35.52 \pm 24.39 \mu\text{g}/\text{m}^3$, $29.73 \mu\text{g}/\text{m}^3$ and $23.49 \mu\text{g}/\text{m}^3$, respectively. These measures reflect the central tendency of the data and where it is centered [15]. Even though a maximum concentration of $656.51 \mu\text{g}/\text{m}^3$ was recorded, the measures of central tendency of PM_{10} concentration levels were uncommonly low and were between 20 and $40 \mu\text{g}/\text{m}^3$. This is mainly caused as the mass of PM_{10} readings were low. Specifically, 50 % of PM_{10} concentrations ranged between $20.55 \mu\text{g}/\text{m}^3$ and $44.13 \mu\text{g}/\text{m}^3$, while 75 % of the readings were below $44.13 \mu\text{g}/\text{m}^3$. Moreover, the boxplot in Figure 2 explained that 75 % of PM_{10} concentrations were located in a narrow range of $44.13 \mu\text{g}/\text{m}^3$, while the remaining 25 % were vacillated in a relatively very wide range of $612.38 \mu\text{g}/\text{m}^3$. In order to clarify this point, the histogram and cumulative frequency curve were used as shown in Figure 3. The Malaysian PM_{10} limit of $150 \mu\text{g}/\text{m}^3$ was set as the upper boundary of the last class.

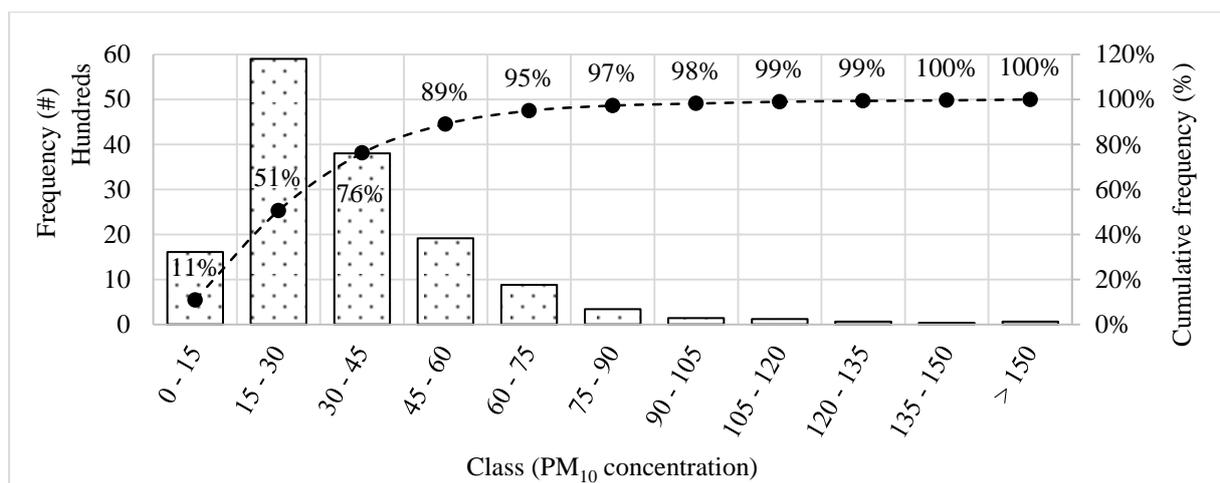


Figure 3: Histogram and cumulative frequency diagram of PM_{10} concentrations

Generally, it is clearly presented in Figure 3 that the mass of the recorded PM_{10} concentrations is concentrated on the left of the figure towards the low concentrations. This case is known as right-skewed distribution [16], in which the most dominant and frequent PM_{10} concentrations would be much closer to zero than the maximum value. It is also illustrated that PM_{10} dominant concentrations ranged from 15 – $30 \mu\text{g}/\text{m}^3$. In addition, the cumulative frequency curve which is presented in Figure 3

as dashed line, indicates that 95 % of PM₁₀ concentration levels were below 75 µg/m³. In other words, and due to the equal sampling time intervals, PM₁₀ concentration level remained below 75 µg/m³ for 95 % of the time during the three weeks of study. The 95 % of time represents 19.95 days out of the 21 days of sampling.

Figure 2 and 3 clearly state that PM₁₀ particles remain low in concentrations most of the time and goes up to alarming levels for very short time span. Therefore, the workers will be exposed to a repetitive, small doses of PM₁₀ for long durations. Thus more focus should be paid on health impact of the long term exposure to small and repetitive PM₁₀ concentrations. Regardless of PM₁₀ guidelines, various studies have proved a positive connection between adverse health effects and long term exposure to repetitive low concentrations of PM₁₀. Schikowski, et al. [17] has found a meaningful and constant detrimental impact of long term exposure to PM₁₀ on lung function, while Dominici, et al. [18] and Heinrich, J., et al. [19] linked the long term exposure of small PM₁₀ concentrations with increased mortality.

3.3. Temperature levels (°C), relative humidity (%) and vehicles flow

Air temperature and relative humidity (RH) are important factors that influence occupant thermal comfort. Temperature levels inside the loading dock fluctuated between 30.46 °C and 34.19 °C with a mean of 32.19 ° ± 0.46 °C. Matsushita (1993) recorded almost the same range of temperature inside underground car parks in Japan [3]. According to the applicable Malaysian guidelines [20], the recommended range for indoor temperature is 23° C to 26° C. Therefore, indoor climate of the study area is poor. On the other hand, indoor relative humidity recorded a minimum and maximum value of 43.90 % and 67.9 % respectively. The American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) stated that the recommended range for acceptable indoor relative humidity limit is 30 % to 65 % [21]. Indoor relative humidity slightly violated the maximum limit but most of the time it followed the acceptable pattern.

Multiple linear regression (MLR) analysis was used in order to create a prediction model that can estimate PM₁₀ concentration based on the previous hour concentration, indoor temperature and relative humidity. The analysis showed a significant correlation between PM₁₀ concentration and the parameters with $P < 0.05$ at the 95 % confidence level. The multiple R and R^2 were 0.91 and 0.83, respectively. Looking at details, the previous concentration and indoor temperature showed stronger correlation with PM₁₀ concentration than relative humidity with P values almost zero. The P value for relative humidity was > 0.05 . The analysis results is shown in equation 1.

$$PM_{10} \text{ concentration} = -13.78 + 0.91 \times \text{Previous concentration} + 0.58 \times \text{Temp} - 0.03 \times \text{RH} \quad (1)$$

MLR conducted for the second time and produced an equation that can predict PM₁₀ concentration based on the number of vehicles that enter or leave the facility is as shown is equation 2.

$$Y = 93.681 - 0.187 \times X \quad (2)$$

Where Y is PM₁₀ concentration and X is the number of vehicles. The model was significant since the P vlaue was < 0.05 . The multiple R and R^2 were 0.80 and 0.63, respectively.

4. Conclusion

PM₁₀ concentration levels inside the underground enclosed loading dock were in compliance with the applicable air quality guidelines. Even though, the workers will be under long-term exposure to repetitive small concentrations of PM₁₀. The effects on workers should be studied due to long exposure duration and mitigating measures should be taken. Moreover, ambient and indoor air quality guidelines are being used in order to evaluate the indoor air quality of underground confined spaces. However, the underground enclosed micro-environment cannot be considered neither as ambient nor indoor environment. This issue raises the need of enclosed air quality guidelines.

5. References

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