Characterization of PM2.5 and Indoor-Outdoor (I/O) Ratio in the Indoor Office Connected to the Chemical Production Plant in Gebeng Industrial Zone, Pahang Malaysia

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ABSTRACT

This study aims to characterize $PM_{2.5}$ in terms of mass concentration, polycyclic aromatic hydrocarbons (PAHs) and elementals concentrations bound to $PM_{2.5}$, and to determine indoor and outdoor (I/O) ratio of $PM_{2.5}$ in the office which is connected to the chemical production plant. The samples were taken for every 8 hours during working days at five sampling points (outdoor environment, production plant, and indoor office). The samples were analysed by using Inductively Coupled Plasma-Mass Spectrometry and Gas Chromatography- Flame Ionization Detector to determine the elementals and PAHs bound to PM2.5, respectively. The results indicated that the mass concentrations of PAHs and elementals (were below the recommended values of World Health Organisation. However, *Si* was found to be the most abundant element and $PM_{2.5}$ were noncompliant with the Permissible Exposure Limit. The I/O relationships for office and production plant revealed that the source of pollutants are mainly contributed by the outdoor sources.

INTRODUCTION

Indoor air quality (IAQ) is a basic determinant of a healthy life, people's wellbeing, and comfort, and productivity of building occupants. The interactions between the site, climate, building system, construction techniques, contaminant source, and human activities are the factors that affect the quality of indoor air. Previous studies carried out the assessment of indoor air in housing area (Schieweck, 2021) school buildings (Hazrin et al., 2017, Vornanen-Winqvist et al., 2020), kindergartens (Chegini et al., 2020), offices (Norhidayah et al., 2016), restaurants (Maryam et al., 2015) and laboratory (Hazrin et al., 2015). The studies of IAQ in the office focused on the urban area (Catalano et al., 2016; Zhang et al., 2020), but limited studies were conducted in the industrial area.

PM2.5 is the most well-intentioned because their concentration can be an indicator of the indoor air quality level with potential health and work performance (Dai et al., 2018). According to a previous study, indoor PM2.5 mainly originated from outdoor sources. Approximately 87% of total indoor PMs comprised indoor PM2.5. Nevertheless, indoor activities and penetration from outdoor environment due to poor airtightness of buildings, and infiltration mechanism can be significant factors of the larger concentration of indoor PM2.5 (Zhang et al., 2020). Regarding indoor office activities, laser printers, photocopiers and multi-task devices are well-known sources for PM2.5. Whereas, the outdoor sources of PM2.5 generates from industrial activities, road traffic and fuel combustion. In this case, the indoor-outdoor (I/O) ratio can respond to the linkage between indoor and outdoor pollutants to some level such as the relationship between indoor and outdoor pollutants.

PM2.5 has an aerodynamic diameter less than or equal to 2.5 µm with a complex mixture of very small particles and droplets. The smaller size of PM2.5 increases their reactivity and is easily enriched by other compounds such as polycyclic aromatic hydrocarbons, viruses and bacteria and elemental (Kim et al., 2015). Among the sources of PAHs in the ambient environment are coming from incomplete combustion of coal and fossil fuel, and automotive vehicles combustion. PAHs are the criteria air pollutants and carcinogenic. Studies found association of lung cancer and PAHs. Since PAHs are very hydrophobic and tend to bind on PM2.5, inhalation of PAHs bound to PM2.5 should be reduced because of the ability of PM2.5 penetrate deep into respiratory system and cause adverse health effects especially among the vulnerable group (Kumar et al., 2020).

Studies found that trace elements such as Magnesium (Mg), Nickel (Ni), Barium (Ba), Aluminium (Al), Galium (Ga), Selenium (Se) and Cobalt (Co) are also commonly found bounded with PM (Bilo et al., 2019; Jin et al., 2017). Trace elements are easily available on the surrounding emitted from environment and other anthropogenic sources has increase the probability of elements bounded with particles suspended in the air. Study by Jin et al. (2017) recorded that elements with lower molecular weight were highly bounded with coarse particles by rapid volatilization and condensation, while higher molecular weight were more enriched in fine particles due to lower vapour pressure. Similar as other components bounded with PM, these trace elements could enter the body up to the bloodstream and disrupt body function and mechanisms. Some species of elements such Zinc (Zn), Lead (Pb), Cadmium (Cd) and Copper (Cu) are easily mobile in the environment and have more bioavailability to organisms, thus pose greater health risks to human health such as cancer, organ damage and often cause mortality.

According to Sangiorgi et al. (2013), I/O is the ratio between the indoor and outdoor concentration of fine and coarse particles. It is a simple and useful parameter which used as basic factors to point out the indoor and outdoor pollution origins and their correlations (Tran et al., 2014). However, there are some limitation of I/O ratios as the I/O ratio does not able to separate the combination of the concentration of fine and coarse particles from outside that infiltrate indoors and those generated indoors.

Regrettably, there are still no consensus on the regulation or guidelines relates to indoor PM2.5, PAH, and elemental. To fill this gap within the body of knowledge, the objective of this study is to characterize PM2.5 in terms of mass concentration, PAHs, and elementals, and to determine the indoor and outdoor ratio of PM2.5 in the office building. To our knowledge, there is no studies conducted in the office building connected to the chemical production plant at the industrial area.

METHODOLOGY

Site selection

The study was conducted at the office building of the chemical manufacturing industry in the Gebeng industrial area, Pahang, Malaysia. The location of the industry surrounded by several petrochemical and chemical industries and nearby the signalized intersection road. This industry manufactures amorphous silica products with a variety of size from 5 – 10 μm, used as a blocking agent of film and resistance agent of scratches. The office location is adjacent to the cafeteria and smoking area, connecting to the production plant via a door at the second floor. This office consists of two levels of the building. Lobby and testing lab located at the first level, while the meeting room, top management room, finance department room and pantry are located at the second level. Meeting, walking, printing, photo-copying, computing, and drinking are the common activities in the indoor office building. The samples were taken for every 8 hours during working days at five sampling points such as outdoor environment (one location), centre of the production plant (one location), and indoor office (three location). Based on walkthrough observation, 5 sampling points were determined. From the observation, there are two types of air conditioning used in the office building which are the central unit and split unit. However, most of the room used a central unit air-conditioning.

Table 1: Sampling points and description

Sampling point	Description
P1	Outdoor
P2	Ground floor lobby (Indoor)
P3	Meeting room: level 1 (Indoor)
P4	Finance department: level 1 (Indoor)
P5	Production plant (Indoor)

Sample preparation

Prior to sample collection using portable, battery operated dustmate, the glass fiber filters were required to be pre-conditioned in order to remove the moisture. As a precaution step of PAH samples, the glass fiber filters were covered by aluminum foil before and after sampling as a protection from direct sunlight. The glass fiber filters are also stored under -16^{o}C to prevent volatilization of PAHs until the extraction and analysis is completed.

Sample collection

The light scattering instrumentation (Model: Turnkey Dustmate) was used to measure the mass concentration of PM2.5 for 8 hours. Air samples were continuously drawn through the nephelometer, which detected and measured the particle passed through a laser beam. The 25mm in a diameter of filters of this instrument was then collected to determine the chemical concentration of PM2.5 by means of PAHs and elementals. A direct reading instrumentation (Anemometer; Model TSI Instrumentation) was employed to record environmental parameters such as air speed, relative humidity and temperature.

Extraction Process

Different extraction techniques have been developed and applied for extracting PAHs from air samples. ASTM D6209 is a Standard Test Method for Determination of Gaseous and Particulate Polycyclic Aromatic Hydrocarbons in Ambient Air (Collection on Sorbent-Backed Filters with Gas Chromatographic/Mass Spectrometric Analysis) (ASTM, 2013). Technique for extraction of particulate bound-PAH include shaking, Soxhlet extraction (SE), microwave-assisted extraction (MAE), ultrasonication (USE), supercritical fluid extraction, pressurized liquid extraction (PLE), pressurize hot water extraction (PHWE) as well as subcritical water extraction (SWE) combined with instrumental quantification in GC-MS, HPLC-MS, HPLC-FL, GC-FID (López-mahía et al., 2019).

Elemental

Elemental enriched-PM2.5 was extracted by using Microwave Digester (Model: PreeKem WX-6000). 6 ml of HNO_3 and 2 ml of HF was added into the vessel for each sample. The first vessel is a blank and others are for the sample and microwave digester can analyze 6 samples including the blank. The settings of this process are temperature: 120-220^{o}C, pressure: 10-35 atm and extraction period: 27 min. After the extraction process, the sample solution was poured to the 50 ml vial. The sample solution of 0.5 ml was diluted two times with deionized water and filtered using PTFE 0.45-micron syringe before injected to Inductively Coupled Plasma Mass Spectrometry (ICP MS).

Polyaromatic hydrocarbons (PAHs)
The glass fiber filters were cut into smaller pieces and were placed in the 50 ml of conical flask. 30 ml of HPLC-grade dichloromethane (DCM) was poured into the sample and then was placed in the ultrasonic cleaner JAC-1020P. This extraction was conducted within 30 minutes and was repeated 2 times to get maximum extraction. The extract solution was evaporated to a small volume until about 5 mL by using a rotary evaporator at temperature 35^oC. The extract solution was filtered through a membrane filter using PTFE 0.45 µm micro syringe. About1 ml of extract solution was then injected into Gas Chromatography with Flame Ionization Detector (GC-FID) for analysis.

Sample Analysis

Elemental Concentration
The standard of elemental was diluted with 1% of HNO_3 in 50 ml of vial. In order to create a calibration curve in ICP-MS, the aliquots of stock solutions were diluted in 50 ml vial for 2 ppm, 5 ppm, 10 ppm, 15 ppm and 20 ppm. ICP MS was employed to determine the concentration of elemental-enriched PM2.5. It is an analytical instrument that uses radio-frequency inductively coupled plasma configured in series with a mass spectrometer.

PAHs Concentration

The column used in the GC-FID is the Perkin Elmer Elite-5 column (30m x 0.25 mm ID). The oven temperature, inlet temperature and column flow has been set up before running the program. 1 ml of internal standard PAHs was injected into GC-FID and a calibration curve was created. 1 ml of internal standard requires 1 hour to be analyzed by GC-FID. After the calibration curve produced 16 peaks, then a very small quantity (1 mL) of the sample solution was injected into the injection port where it is vaporized and been analyzed for about 1 hour for every sample. The concentration of the PAHs was shown in the PC monitor after 1 hour.

RESULTS AND DISCUSSION

Environmental Condition

Table 2 tabulates the mean value of environmental conditions such as temperature, relative humidity and air speed. The indoor values were compared to the recommended values of Industrial Code of Practise on Indoor Air Quality (ICOP on IAQ) (Department of Occupational Safety and Health, Malaysia, 2010). The temperature and relative humidity were permitted by the ICOP on IAQ (2010), whereas air speed was considered as a low air movement. It was believed that the lower air speed created poor ventilation which avoided a well-mixing and dilution of pollutants in indoor air hence, the concentration of PM2.5 still remained high in indoor air of the building. Pertaining outdoor air speed, it also indicated the light air movement. As expected, the outdoor temperature and relative humidity were higher than indoor environmental parameters due to the industry which was located near the coastal area.

Table 2. The mean value of environmental conditions such as temperature, relative humidity and air speed.

Environmental Condition	Indoor	Outdoor	ICOP on IAQ
Temperature (^0C)	25.4	30.4	23-26
Relative Humidity (%)	59.50	70.47	40-70
Air speed (m/s)	0.041	0.095	0.15-0.50

Mass Concentration of PM2.5

The mass concentrations of PM2.5 were measured in five different points such as outdoor, lobby, meeting room, finance department room and production plant as tabulated in Table 3. It was observed that the production plant shows the greatest concentration of PM2.5, which exceeded the WHO recommended maximum value of PM2.5 is 10 $\mu g/m^3$. The operation in the production plant becomes the important source of PM2.5. In an indoor building, the highest concentration was found in the finance department room because this area is very close to the connecting door to the production plant. It can be assumed that PM2.5 entered the indoor building via the natural ventilation while the building occupants opened and closed the door. The infiltration mechanism also occurred through the opening side at the bottom of the door and small holes at the joining between the door and the door frame. The concentrations of PM2.5 at the lobby and center of office rooms at level 2 are higher than outdoor concentration. The indoor activities such as printing, photo-copying, computing, cleaning, walking, and meeting during sampling period affected the mass concentration of PM2.5. Unfortunately, by looking at the maximum value, all the indoor mass concentration of PM2.5 exceeded the recommended value set by WHO. This condition will generate a negative health impact to building occupants such as respiratory diseases and carcinogenic effects. Since this industry is located near to the signalized intersection road, it can be suggested that the outdoor concentration of PM2.5

was contributed by the exhaust emission from the heavy-duty vehicles like trucks and lorries.

Table 3 Min, Max, Mean and SD of the PM2.5 concentration (µg/m³)

Location	Min	Max	Mean	SD
P1	2.08	8.99	4.72	1.89
P2	4.47	10.23	6.68	1.61
P3	3.66	18.16	7.61	4.53
P4	25.6	40.38	33.64	4.00
P5	39.00	62.11	55.1	12.29

Elemental Composition

The elemental composition (*Al, Si, Ba, Ga, Co* and *Se*) bound with PM2.5 is showed in Table 3. The highest concentration of elementals bound to PM2.5 can be sampled at the production plant. *Ba* and *Si* did not permit the Eight Hours - Time Weighted Average of Occupational Safety and Health (Use and Standards of Exposure of Chemicals Hazardous to Health Regulations 2000) (DOSH, Malaysia). It is believed that Ba uses as an indoor wall preservative that can be presented in the paints and adhesive.

Table 4. Elemental concentration associated with PM2.5 (mg/m3) and SD value.

Elemental (mg/m³)	P1	P2	P3	P4	P5	8-h TWA
	Mean ± SD					
Al	$1.2x10^{-1}$ ± $2.0x10^{3}$	$2.8 x10^{1}$ ± $2.8x10^{-2}$	$2.7x10^{-1}$ ± $9.2 x10^{-2}$	$2.5x10^{-1}$ ± $9.2x10^{-2}$	3.5E+00 ± 1.0E+00	10
Si	$9.7 x10^{1}$ ± 4.2	$1.8 x10^{1}$ ± $1.2 x10^{1}$	5.4 ± 2.0	$1.9 x10^{1}$ ± 1.1	2.5E+01 ± 5.0E+00	10
Ba	$8.0 x10^{-1}$ ± $3.0 x10^{-1}$	2.5 ± $4.6 x10^{-1}$	2.0 ± 1.2	2.8 ± 1.1	3.2E+00 ± 9.2E-02	0.5
Ga	$2.9 x10^{-2}$ ± $1.0 x10^{-3}$	$8.6 x10^{-2}$ ± $6.2 x10^{-2}$	$6.9 x10^{-2}$ ± $1.2 x10^{-2}$	$9.3 x10^{-2}$ ± $2x10^{-3}$	1.1E-01 ± 2.3E-02	N/A
Co	$2.0 x10^{-3}$ ± $1.0 x10^{-3}$	N/A	$1.1 x10^{-2}$ ± 1.0	N/A	9.5E-03 ± 2.0E-03	0.02
Se	$2.0 x10^{-3}$ ± $1.2 x10^{-3}$	N/A	$2.0 x10^{-3}$ ± $1.0 x10^{-3}$	2.0 x10-3 ± $1.5 x10^{-2}$	3.0E-03 ± 1.7E-02	0.2

The abundant of *Si* is contributed by the production process itself, whereas the end product of this industry are silica gels, precipitated silica, and modified silica products. The workers tend to get negative health impacts such as silicosis due to Si exposure via inhalation. *Al, Co* and *Se* permitted to the standard limit recommended by DOSH Malaysia by referring to the USECHH Regulation, 2000. The presence of *Al* in the indoor building due to the use of alumina as the base materials that used to transform into functional materials. *Se* used in photocopier machine for reproducing and copying documents, and letters.

Polyaromatic hydrocarbons (PAHs)

The occurrence of PAHs bound in PM2.5 is plotted in Figure 1. Acenapthylene (0.001 ppm - 0.002ppm), phenanthrene (0.001 ppm - 0.002ppm), fluoranthene (0.001 ppm), pyrene (0.001 ppm), benz(a)anthracene, chrysene (0.002 ppm - 0.004ppm), benzo(a)fluoranthene (0.001 ppm - 0.002ppm), and benzo (a)pyrene (0.001 ppm - 0.002ppm). It can be assumed that the occurrence of PAHs associated with PM2.5 is due to the anthropogenic outdoor source (such as traffic emission, industrial emission and smoking activity at outside area of building) and the types and frequency of activities in indoor office. The dust accumulated on the cooling fans of computer boxes and next, re-emitted or re-suspended in indoor environment. In addition, the dust settled on the heated plastic materials of computers also can be a source of PAHs in indoor building.

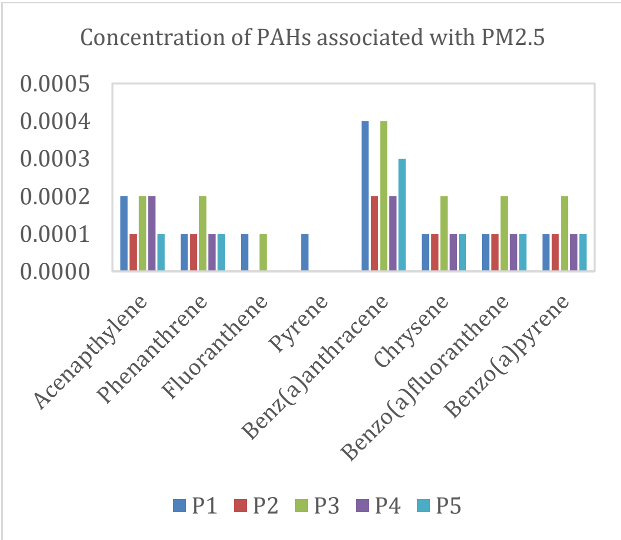

Figure 1. The concentration of PAHs (ppm) associated with PM2.5.

Indoor/outdoor (I/O) ratio

I/O ratio typically indicates the relationship between indoor and outdoor pollutants concentrations, which is very easy to comprehend and broadly utilized. Table 4 tabulates the I/O ratio of the pollutants such as $PM_{2.5}$, elementals and PAHs. The I/O ratio for office and production plant indicates that $PM_{2.5}$, elemental concentration and PAHs are lower than 1.0. It suggests that the $PM_{2.5}$ and elementals are generated from the production plants due to a gigantic concentration of $PM_{2.5}$ and Si. While, the I/O ratio for office and ambient air reveals that $PM_{2.5}$ and elementals are solely generated from the indoor source. The source of PAHs are outdoor smoking activities, industrial emission and traffic activities which near to the office.

Table 4. I/O ratio of PM2.5, elementals and PAHs.

	Mean ± SD	
Pollutants	I/O (ambient environment	I/O (production plant)
PM2.5	3.38	0.30
Elementals	3.17	0.19
PAHs	0.96	0.86

CONCLUSION

The assessment of PM2.5 characteristics such as mass concentration, PAHs and elemental concentrations, and I/O ratio were conducted. Indoor sampling locations such as production plant and finance department showed the mass concentration of PM2.5, the elemental composition was exceeded the permissible standard limit of The Occupational Safety and Health (Use and Standards of Exposure of Chemicals Hazardous to Health) Regulations 2000 (USECHH Regulations 2000). This can lead to the creation of the unhealthy working environment, which give negative health impact to workers. PAHs also can present in indoor building likes Acenapthylene, phenanthrene, fluoranthene, pyrene, benz(a)anthracene, chrysene, benzo(a)fluoranthene, and benzo (a)pyrene. The greater I/O relationship for the office and the production plant indicated that the $PM_{2.5}$, elementals and PAHs are generated from outdoor source (production plant). This research provides a piece of baseline information on the pollutants in the indoor environment especially for an office building located near or attached to the production plant.

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