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PHYSICOCHEMICAL CHARACTERISTICS OF PM10 AND PM2.5 IN INDOOR BUILDING

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ABSTRACT

The phsysicochemical characteristics (mass concentration, indoor-outdoor relationship and heavy metals associated with particles) of PM10 and PM2.5 in indoor building which located in industrial area were examined. A walkthrough observation was conducted to identify the sources of the potential contaminants. The concentrations level of particles were collected by using a very fast response hand-held calibrated instrument and the heavy metals which associated with PM10 and PM2.5 were analysed by using Inductively Coupled Plasma-Mass Spectrometry (ICP-MS). Results suggest that both of PM10 and PM2.5 at point E were permitted to the US Environmental Protection Agency (US EPA). Besides, for the indoor PM2.5, only point B (33.56µg/m^3) was not conformed with the standard limit which recommended by WHO (25µg/m^3). However, indoor concentrations of PM10 are not conformed with the standard limit value which is set by WHO (50µg/m^3). Apart from this, it was found that six heavy metals such as *Al, Si, Se, Co, Ba,* and *Ga* which associated with PM10 and PM2.5in the indoor and outdoor environment of the building of chemical industry. In indoor building, most of the concentration of *Si* are higher than Permissible Exposure Limit - Time Weighted Average (PEL-TWA) which provide the unhealthy indoor air.

Keywords: indoor air, PM10, PM2.5, heavy metals. I/O relationship.

INTRODUCTION

Particulate matter (PM) is the complex mixture of small solid particles and different sizes of liquid droplets that suspended in the air. They are considered being one of the atmospheric pollutants that display as a broad class of chemically and physically multiple substances and cause air pollution no matter in indoor or outdoor building (Abdullahi *et al.,* 2013). There are three types of PM which classified according to the size of the particles such as coarse, fine and ultrafine particulate matters. However, the main types of PM that mostly exist in the atmosphere in the indoor building are fine and coarse particles with the aerodynamic diameter of 2.5µm or less and 10µm or less respectively. There are lot of sources that generate particles in the indoor environment as well as outdoor environment of a building which include indoor human occupants, laser printer, photocopier (Tang *et al*., 2012) heating, ventilation and air conditioning (HVAC) system (Fisk *et al*, 2000), computer (Wensing *et al.,* 2008), building materials, as well as the indoor and outdoor activities such as walking, cleaning, and vacuuming (Abt *et al*., 2000). There is a fact that people who work in the indoor building such as office, printing room, classroom, museum, library, and hospital are spending most of their time in the indoors rather than outdoors.

Numerous scientific researchers have been conducted on the human exposure to particles with health problems such as premature death in people with heart or lung disease, nonfatal heart attacks, irregular heartbeat, aggravated asthma, decreased lung function, and increased respiratory symptoms, such as irritation of the airways, coughing or difficulty breathing. The failure to take action immediately and efficiently on the problem of poor indoor air quality (IAQ) could have been the disastrous consequences on human health (Norhidayah *et al*., 2013). In 2009, the World Organization Health (WHO) prepared a report on Global Health Risks: Mortality and Burden of Disease Attributable to Selected Major Risks. This report proposed that indoor air pollution is responsible for 2.7% of the global burden of disease. One of the effective step to determine the level of human exposure, transport and behavior of particles in air can be carried out via the determination of physicochemical properties of particles. The study on physicochemical properties of particles can determine the level of toxicity and, transport and behavior of particles in air. For example, the measurement of mass concentration of particles are used to assess the level of exposure of building occupants. Lonati *et al*. (2011) stated that there is a significant portion of building occupants where the personal exposure to PM in the indoor environment might be higher than outdoor environment. This indicates that there are several significant processes that affecting the concentration levels of particles in the indoor building such as the penetration of outdoors sources into indoor spaces via open doors and windows, as well as through the building envelope.

Several studies have been conducted and discussed about the indoor/outdoor relationship in order to find whether the indoor environment is developed with fine and coarse particles if compared with outdoor environment (Chen and Zhao, 2011). 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 (Sangiorgi *et al*., 2013), it only

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provides the general information about the pollutant origins, without distinguishing each specific source (Tran *et al*., 2014). The concentration ratio of the PM10 fraction mass to the PM2.5 fraction mass averaged over all indoor samples is larger than the mean mass ratio for the outdoor samples. Most ratios for the heavy metals are also larger than their corresponding outdoor values which indicate that the abundances of the PM2.5 constituents are larger for the indoor particles than for the ambient particles (Salma *et al*., 2013). This information implies that there are some indoor emission sources for the particular heavy metals in the indoor environment of the building.

Although there are established scientific researches assessing the mass concentration of particles, indoor-outdoor relationship and the elemental composition of PM with different size fraction in schools, kitchens and retirement homes, apartments, none of them analyzed these properties in the building which located at industrial area (Buonanno *et al*., 2013;Fromme *et al*., 2008; Polidori *et al*., 2007), none of them explored simultaneously the PM mass concentration and the heavy metals composition of the different faction sizes of PM.

METHODOLOGY

Site selection

This research was conducted in the indoor building which attached to the production plant of the chemical industry in the East Coast of Peninsular of Malaysia. It is located in the land zone of industry, where there are some others chemical, petrochemical and manufacturing companies located near to this industry. The raw materials which utilized in the production plant are sodium silicate and sulphuric acid, which undergo three processes such as wet end system, dry end system and waste water treatment plant system for the manufacturing micronized silica.

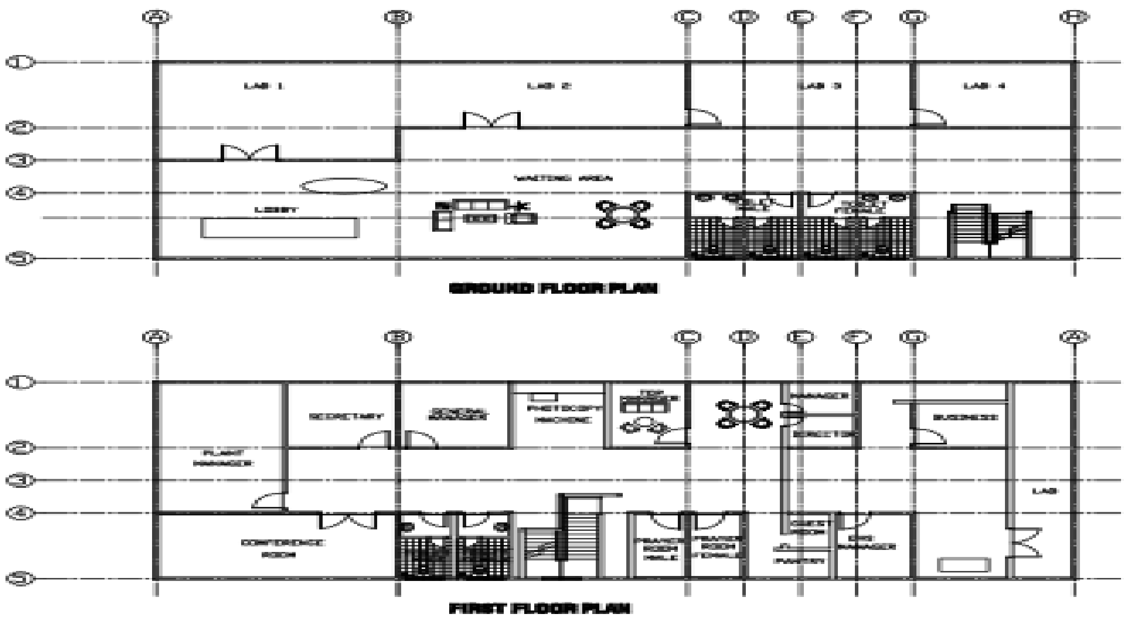

Figure-1. Layout design of indoor building.

The process of silica production indirectly causing the presence of the heavy metals associated with the PM10 and PM2.5 particles in the indoor and outdoor building of this chemical industry. Figure-1 and Table-1 show the layout design of the indoor building and the description of sampling points in this building respectively.

Table-1. Sampling points in indoor building.

Sampling point	Location	Description
A	Level 2 (Indoor)	Near to printer
B	Level 2 (Indoor)	Finance department (filing and partition), near to exit door
C	Level 2 (Indoor)	Exit door (connect to production plant)
D	Level 1 (Indoor)	Lobby
E	Level 1 (Outdoor)	In front of the entrance door

Sampling of PM10 and PM2.5

A calibrated handheld dust analyzer (Model: Turnkey Dustmate, 11642) with a very fast response was used to measure the area mass concentration of PM10 and PM2.5. This instrument attached with the Whatman GF/A 25 mm filter as a sampling media. The sampling was conducted at least 6 hours with interval 15 minutes for every sampling point. During sampling, physical parameters such as relative humidity, temperature and air speed were measured by using vane and hotwire anemometer (Model 9555, TSI Inc, USA).

Analysis of PM10 and PM2.5 particles associated with heavy metals

After sampling, the Whatman GF/A 25 mm filters attached with dust analyzer were digested with hydrofluoric acid and nitric acid in microwave digester (Model: Preekem WX6000). This process allows the solid sample of filters was transformed into the liquid form. Then, the liquid samples were injected into Inductive Coupled Plasma-Mass Spectrophotomer (Model: NexIon 250, Perkin Elmer) to measure the concentration of heavy metals associated in the particles.

RESULT AND DISCUSSIONS

Physical parameters in indoor and outdoor of building

Table-2 depicts the environmental parameters such as temperature (T), relative humidity (RH) and air movement in indoor and outdoor of building. These values were compared to the acceptable limit values, which stated in Industry Code of Practice on Indoor Air Quality, Malaysia as shown in Table-3 (Department of Occupational Safety and Health, Malaysia) .Prior to maintain a good IAQ, the acceptable limit of each IAQ parameter must be complied. The mean temperature and relative humidity in indoor building are in the range of acceptable values.

Table-2. Physical parameters in indoor and outdoor of building.

Sampling point	Parameter	Mean value	Standard deviation
Total Indoor	T (^{0}C)	25.4	0.49
	RH (%)	59.50	3.29
	Air movement (m/s)	0.041	0.18
Outdoor	T (^{0}C)	30.4	1.17
	RH (%)	70.47	9.16
	Air movement (m/s)	0.095	0.022

Table-3. Acceptable limit value of physical parameters of indoor air quality (DOSH Malaysia, 2010).

Parameter	Acceptable limit value
Temperature (°C)	23 - 26
Relative Humidity (%)	40 - 70
Air movement (m/s)	0.15 - 0.50

Air movement in indoor is lower than the acceptable limit. It was generated by uneven air conditioning flow in building. The lower air movement in the indoor building led to the smaller air exchange rate, which caused the accumulation of both PM10 and PM2.5 in the indoor environment (Chithra and Shiva Nagendra, 2013). However, the outdoor physical parameters are not compared with the acceptable limit values since there are no established guidelines for outdoor and it is strongly influenced by the climate.

Mass concentration of PM10 and PM2.5

The mass concentration of PM10 and PM2.5 were measured at five sampling points as pointed in Figure-2. However, the increase sequence of PM2.5 were slightly different with the PM10. These findings show that the lowest mass concentration of PM10 was emitted at point E (0.89µg/m^3), followed by point D (124.19µg/m^3), point C (160.35µg/m^3), point A (195.41µg/m^3) and B (262.01µg/m^3). The lowest mass concentration of PM2.5 is located at point A (5.69µg/m^3), then increased at point D (7.15µg/m^3), E (4.62µg/m^3) and C (18.06µg/m^3). Point B (33.36µg/m^3) depicts the highest mass concentration of PM2.5 which similar with the PM10. It is due to the activities which carried out at this point such as printing, photocopying and filing. These activities have high tendency to generate PM2.5 in indoor air building. Whereas, the lowest mass concentration of PM2.5 is situated at point E. It assumes that the dilution factor which creates by a wind speed play a significant function in dispersing the PM2.5 in ambient air. As can be seen in Figure-2, the concentrations of PM2.5 and PM10 are fluctuated due to the behavior of particles in air such as deposition and re - suspension of particles in indoor building.

Pertaining the compliance of regulation, the mean mass concentration values of PM10 and PM2.5 were compared with US EPA and WHO. As can be seen in Figure 3, Point A, C and D (except Point B) in indoor of PM2.5 were permitted to the recommended standard limit value of WHO (25µg/m^3). Unfortunately, all of the sampling points for indoor PM10 are considerably high since they were not permitted to WHO standard limit

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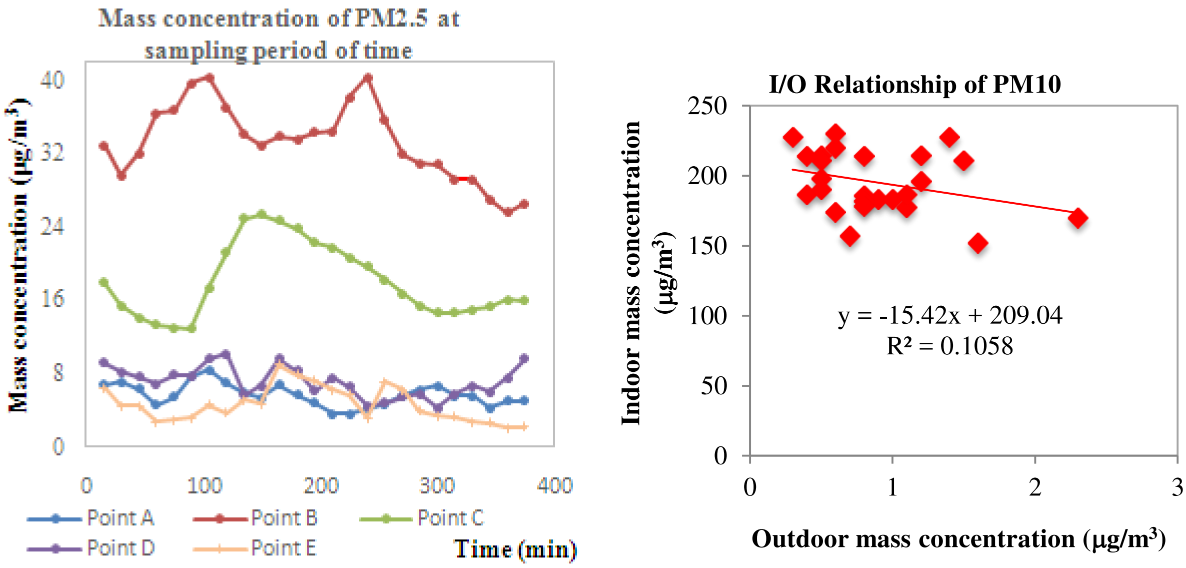
(50µg/m^3).Based on the walkthrough observation result, the inlet for ventilation system of indoor building is located in the production plant. This condition is a vital factor which contributes to high mass concentrations of PM10. It believes that this condition will provide to unhealthy condition of working environment in indoor building due to non-conformance of recommended standard limit whichis set by WHO.

I/O relationship of PM10 and PM2.5

Figures-4 and 5 illustrate the concentration of indoor vs. outdoor concentration of both particles. By referring to the scattered plots, the value of the coefficient of determination (R^2) between the indoor and outdoor data is used as an indicator of the degree to measure whether there is any infiltration of PM10 and PM2.5 from outdoor to indoor workplace building (Geller *et al.*, 2002). In Figure-5, the correlation coefficient of regression line of PM10 is y= -0.0302x+6.7929, shows a negative value, which indicates that the line slopes downward in the graph.

Based on the coefficient of determination, R^2, it indicates there is no correlation between the indoor and outdoor data as the R^2 value is 0.105.



(a) (b)

Figure-2. Mass concentration of particles at sampling period of time; a) PM2.5 and b) PM10.

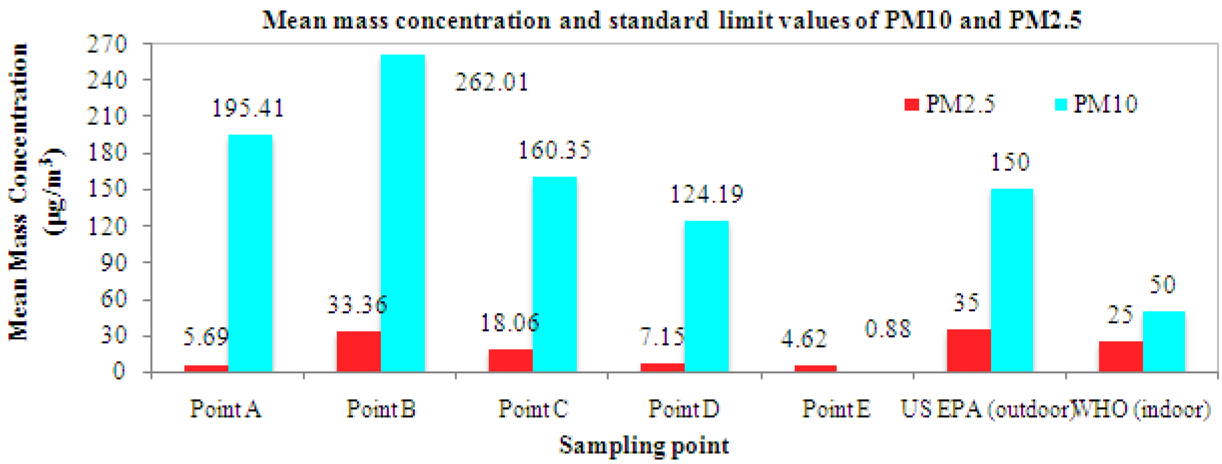


Figure-3. Mean mass concentration of PM10 and PM2.5 at sampling period of time.

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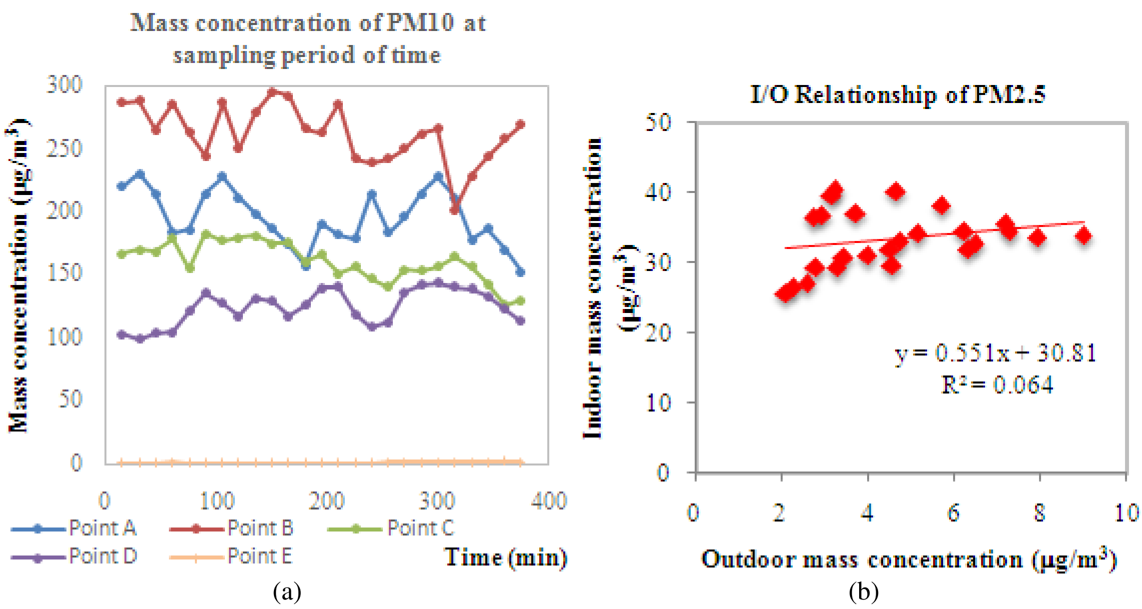

Figure-4. Indoor / Outdoor relationship of a) PM10 and, b) PM2.5.

Table-4. Concentration of heavy metals associated with PM10 and PM2.5.

Type of heavy metals	Concentration of heavy metals in different locations (ppm)									
	A		B		C		D		E	
	$PM_{2.5}$	PM_{10}	$PM_{2.5}$	PM_{10}	$PM_{2.5}$	PM_{10}	$PM_{2.5}$	PM_{10}	$PM_{2.5}$	PM_{10}
Al	0.27	0.7	0.24	0.3	0.44	1.11	2.77	0.35	0.12	0.021
Si	5.36	14.84	3.04	8.77	4.64	14.26	17.9	15.87	9.72	5.59
Se	0.0021	0.019	0.023	0.032	0.012	0.011	-	-	0.005	-
Co	0.0095	-	-	-	-	0.011	-	0.044	0.002	0.006
Ba	2.01	2.54	2.75	2.84	1.24	3.22	2.52	1.23	0.8	0.32
Ga	0.069	0.087	0.093	0.098	0.042	0.11	0.086	0.045	0.029	0.012

Heavy metals associated with PM10 and PM2.5

Table-4 tabulates the concentration of heavy metals which associated with indoor and outdoor particles. Only six heavy metals were presented in PM10 and PM2.5 which are Aluminium (*Al*), Silica (*Si*), Selenium (*Se*), Cobalt (*Co*), Barium (*Ba*), and Galium (*Ga*). The most significant among those six types of heavy metals which associated with PM10 and PM2.5 is *Si*, found at point D. It is due to the location of point D which is adjacent with the production plant which mainly utilized the sodium silicate as a raw matetrial in producing a micronized silica. *Si* also used as one of the base materials that used to transform into functional ingredients such as silica gels, precipitated silica, and modified silica products. However, the emissions from diesel engines could contribute to the concentrations of Si found in ambient PM10 and PM2.5 (Lin *et al*., 2005) and it might be raised from geological material such as soil and road dust (Chithra and Shiva Nagendra, 2013).

It was detected in the indoor building of this chemical company may be due to the contribution from the nearby industries by wind (Tovalin-Ahumada *et al*., 2007).

With regard to the compliance of recommended standard value, the findings of heavy metals concentrations were compared with the Permissible Exposure Limit - Time Weighted Average (PEL-TWA) which published in Use and Standard of Exposure on the Chemical Hazardous to Health (USECHH Regulation, 2010) (DOSH, Malaysia). Overall, the concentration of heavy metals which associated with PM10 and PM2.5 are permitted to USECHH Regulation except *Si*.

CONCLUSIONS

The physicochemical characteristics of PM10 and PM2.5 in indoor and outdoor building of chemical production plant were assessed in terms of mass concentration, indoor/outdoor relationship and concentration of heavy metals associated in particles.

Pertaining to the compliance of mass concentration, PM10 are obviously not permitted to the recommended standard limit. Based on the indoor-outdoor relationships of both particles, the trends are similar since the sources of particles are solely contributed from the outdoor due to weak correlation coeffients. Six heavy metals are associated with particles such as *Al, Si, Se, Co, Ba*and *Ga*. The concentration of *Si*is not complied to the

USECHH regulation due to the higher concentrations compared with PEL-TWA.

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