Development of Particle Distribution Estimation (PDE) Model Based on Particulate Mass Concentration for Indoor Ambient Air Monitoring

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Particulate Matter (PM) mass concentration is one of the key elements in determining Air Quality Index (AQI). Conventionally, PM mass concentration is measured using Federal Reference Method (FRM) which apply the filter based gravimetric method. While the mass concentration may be used as a threshold limit on particulate matter exposure, recent studies had shown that particles distribution may provide better insight on the adverse effect of particulate matter exposure. In this study a Particle Distribution Estimation Model (PDE) was developed for determination of particle distribution based on particulate mass concentration. The model was developed using correlation between Particle distribution and particulate mass concentration from purple Air-II (PA-II) an optical based research grade instrument. The Particle Distribution Estimation (PDE) Model was evaluated at an outdoor environment. The estimated particle distribution from the PDE shows excellent correlation with the actual particle distribution from the reference instrument with R2is higher than 0.8.

Keywords: PM2.5; Particle Distribution; Particulate Matter; Air Quality

I. INTRODUCTION

Particulate Matter (PM) mass concentration is one of the key indicators in determining Air Quality Index (AQI) (Brunekreef & Holgate, 2002; Lee, 2010). Various epidemiological studies have reported the health threat proposed by PM to our cardiovascular system (Chuang *et. al.,* 2011; World Health Organization, 2014). Regulatory bodies such as the US Environmental Protection Agency (EPA), has set a certain threshold limit for particulate matter exposure based on mass concentration (Esworthy, 2015).

Conventionally, the PM mass concentration was monitored through the gravimetric method which is also known as the Federal Reference Method (FRM) (Hall *et. al.,* 2014).Though being known to provide high accuracy on PM mass concentration, the gravimetric method has always hindered deeper understanding on health threat of PM especially to those who are exposed in vicinity. The high cost of deployment and long sampling interval (Chow & Chow, 2012; Schmidt-Ott & Ristovski, 2006) of the gravimetric method has made it unfavourable for large monitoring network hence limiting better understanding on spatial and temporal PM concentrations.

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While the PM mass concentration may be good indicator for PM exposure, recent studies also reported that the particles distribution may provide better insight on particulate matter exposure (Weijers *et. al.,* 2004). The severity of particulate matter exposure is measured based on its penetration rate into our respiratory tract which is classified based on their aerodynamics diameter (Brown *et al.*, 2013). The smaller the particle size the more deeply it will penetrate the respiratory tract causing more adverse effect. Therefore, it is important to consider the particle distribution in determining PM exposure.

In this study, a Particle Distribution Estimation Model (PDE) was developed for determination of particle count distribution based on particulate mass concentration. The model was developed by correlating the reported particle distribution with the reported PM mass concentration from the purpleAir-II (PA-II).

II. RESEARCH METHODOLOGY

A. Reference Instrument Description

PA-II is a research grade instrument that had been evaluated and compared with two FEM instruments namely the MetOne Beta Attenuation Method (BAM) which is certified FEM for PM 2.5 and PM 10.0 and the GRIMM which is certified FEM for PM2.5 in both laboratory and field evaluation (Pa-ii, Pm, Pm, Ii, & An, n.d.). The evaluation summary between PA-II against the FEM instrument is as shown in Table 1.

Table 1: Evaluation Summary between PA-II and FEM instrument

Instrument	Evaluation Period	R²		
		PM 1.0	PM 2.5	PM 10.0
FEM	1 Hour		**0.92**	**0.64**
	24 Hour		**0.97**	**0.74**
PA II	1 Minute	0.98	**0.97**	0.70
	1 Hour	0.98	**0.98**	0.72
	24 Hour	0.99	**0.98**	0.78

The PA-II operates based on laser scattering employing the PMS5003 particulate matter sensor from Plan tower for its detection. The PA-II is capable of reporting particle distribution and mass concentrations simultaneously and it also comes with data logger that save data approximately every 1-minute interval.

B. Reference Instrument Reported Particle Distribution

In this study, we have classified the particle distribution channel into five smaller range as shown in Table 2. The particle size ranges were then used to determine each of the mean particle diameter in each respective channel. This mean diameter will be used to obtain the volume of particle for derivation of the Particulate Distribution Estimation (PDE) Linear Model.

Table 2: Particle Size Range

Channel	Range	Particle Size Range, μm	Mean Diameter, μm
A	0.3 μm >x ≥ 0.5 μm	0.4, 0.5	0.45
B	0.5 μm >x ≥1.0 μm	0.6, 0.7, 0.8, 0.9, 1.0	0.80
C	1.0 μm >x ≥ 2.5 μm	1.1, 1.2, 1.3, 1.4, 1.5, …, 2.5	1.80
D	2.5 μm >x ≥ 5.0 μm	2.6, 2.7, 2.8, 2.9, 3.0, … , 5.0	3.80
E	5.0 μm >x ≥ 10.0 μm	5.1, 5.2, 5.3, 5.4, 5.5, …, 10.0	7.55

C. Reference Instrument Reported Mass Concentration

The PA-II report mass concentration in three bin channels namely PM 1.0, PM 2.5 and PM 10.0 in the unit of μg/m³. This mass concentration is represented using two algorithms which can be classified as Standard Atmosphere Algorithm (AT) and Industrial Algorithm (CF). The AT algorithm represents the pollutants commonly found in an indoor environment whereas the CF algorithm reports reading based on industrial metal particle densities and is suitable for environments such as an industrial production workshop (Tan, 2017). Since this experiment is conducted in an indoor environment, the mass concentration reported using AT algorithm was selected in this study.

D. Site Description

This study was set up in an indoor environment. The site selected was Material science lab which is located in the Faculty of Science and Natural Resources, University Malaysia Sabah (N 6°1'54.2094'', E 117'11.316'') for a period of seven days from 10ᵗʰMarch 2018 until 17ᵗʰMarch 2018. The PA-II was placed approximately 1.5 m from the ground and could continuously sample the ambient air without any stimulation. The source of the sampled air throughout the sampling period mostly come from the natural ventilation of the lab which resourced from either the exchange of air during door opening or air from the air conditioner.

Meteorological conditions during the evaluation period were normally distributed. The lowest temperature, relative humidity and pressure recorded during this study were 26.7 °C, 40%RH and 1006 Pa respectively, while the highest temperature, relative humidity and pressure were 33.8 °C, 57 %RH and 1012 pa respectively. Hourly PM 1.0 mass concentrations varied from 1.44 to 21.78 μg/m³, PM 2.5 from 2.47to 32.21 μg/m³ and PM 10.0 from 2.69 to 32.82 μg/m³.

III. RESULTS AND FINDING

A. Derivation of Particulate Distribution Estimation (PDE) Linear Model

Optical instrument does not directly measure the mass concentration of PM, the mass concentration is calculated based on particle size distribution under assumptions that all particles is spherical and density is known (Liu *et. al.,* 2017). The derivation of particle count to mass concentration is given by(Friedlander, 2000);

$$mass\ concentration,\ Kg/m^3 = \rho \int \frac{\pi d_p{}^3}{6}.N(d_p) \quad (1)$$

Where ρ is the density function ,$\frac{\pi d_p{}^3}{6}$ is the particle size volume in respect to the mean diameter,d_p(Refer to Table 3) and $N(d_p)$is the total number of particle in the particle bin channel. In this study, the PDE model was derived based on the inversion of equation (1) such that the total number of particles is equal to

$$\int N(d_p) = \frac{mass\ concentration,\ kg/m^3}{p \times (\pi d_p 3/6)} \quad (2)$$

In this study, we identified the PM 1.0 to be contributed by summation of particle in channel A and B whereas the PM 2.5 is contributed by particle in channel A to C and the PM 10.0 is contributed by particle in channel A to E. Table 3shows the summary of each contributing particle distribution channel and their confidence interval in respect to the mass concentration as well as the contributing density function for each mass concentration which were obtained by dividing each mass concentration channel with the summation of the total volume from each of the contributing particle distribution bin. Figure 1 shows the density function plot.

Table 3: Summary of contributing particle distribution channel to mass concentration

	Contributing Channel	R^2	Confidence Interval, CI					Density Function, kg/m³	
			A	B	C	D	E	ρ_{med}	ρ_{Q1}
PM 1.0	A + B	0.99	35%	65%	X	X	X	4.91 x 10¹⁶	4.39 x 10¹⁶
PM 2.5	A + B + c	0.99	16%	31%	53%	X	X	3.27 x 10¹⁶	3.03 x 10¹⁶

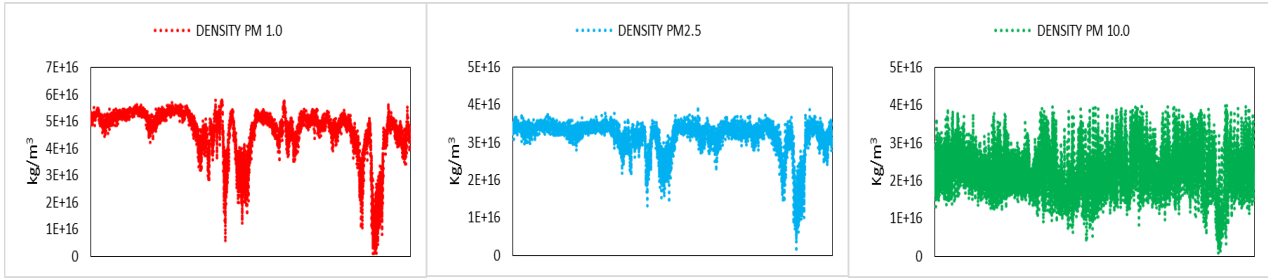| PM 10.0	A + B + C + D +E	0.99	11%	20%	33%	16%	20%	2.19 x 10^{16}	1.76 x 10^{16}

Figure 1: Density function plot for PM 1.0, PM 2.5 and PM 10.0

Based on the density function in table 3, it was observed that the density function varies for each particulate mass conversion. This is most likely due to particle composition (Wang *et. al.,* 2015). Therefore, it is crucial to identify which density function should be applied. Using the confidence interval from each channel in table 3, the density function for each of the respective particle distribution channel can be determined. If the CI is less than 50%, the First quartile density function, ρ_{Q1} will be applied whereas if more than 50%, the Second quartile density function, ρ_{med} will be applied.

Therefore, by using equation (2) and each of the of the designated density function for each channel in respect to the mass concentration in Table 3, the estimated particle distribution from each respective channel can then be derived such that from the PM 10.0 mass concentration the particle distribution is given by;

$$Particle\ Count\ A = \frac{PM\ 10}{(1.76 \times 10^{16} Kg/m^3)(\pi d_{pA3}/6)} \times$$
$$0.11\ (CI) \qquad (3)$$

$$Particle\ Count\ B = \frac{PM\ 10}{(1.76 \times 10^{16} Kg/m^3)(\pi d_{pA3}/6)} \times$$
$$0.20\ (CI) \qquad \mathbf{(4)}$$

$$Particle\ Count\ C = \frac{PM\ 10}{(1.76 \times 10^{16} Kg/m^3)(\pi d_{pA3}/6)} \times$$
$$0.33\ (CI) \qquad \mathbf{(5)}$$

$$Particle\ Count\ D = \frac{PM\ 10}{(1.76 \times 10^{16} Kg/m^3)(\pi d_{pA3}/6)} \times$$
$$0.16\ (CI) \qquad \mathbf{(6)}$$

$$Particle\ Count\ E = \frac{PM\ 10}{(1.76 \times 10^{16} Kg/m^3)(\pi d_{pA3}/6)} \times$$
$$0.20\ (CI) \qquad \mathbf{(7)}$$

B. Validation of the Particulate Distribution Estimation (PDE) Linear Model

To evaluate the developed model, the experiment setup was replicated in a new environment in an outdoor environment at Kg. Marakau, Ranau, Sabah (N 5°57' 28.8", E 116°41' 13.2") for a period of seven days from 19[th]April 2018 until 26[th]April 2018side by side with our developed particulate matter measurement device (Chee *et. al.,* 2018).The Meteorological conditions in the new site during the evaluation period were normally distributed.

The lowest temperature, relative humidity and pressure recorded during this study were 30.55∘C, 67.26%RH and 1010 Pa respectively, while the highest temperature, relative humidity and pressure were 32.7∘C, 72 %RH and 1013Pa respectively. Hourly PM 1.0 mass concentrations varied from 17 to 158μg/m³, PM 2.5 from 52to 255μg/m³ and PM 10.0 from 57 to 283μg/m³.

The mass concentration and particle count from the new site were monitored through the PA-II instrument and the data were applied to the PDE model to obtain the estimated particle distribution. The estimated particle count was then correlated with the actual particle count from the PA-II and the regression plot is as shown in Figure 2.

Both estimated and actual particle count in this study were represented in the unit of particles/0.1 L.
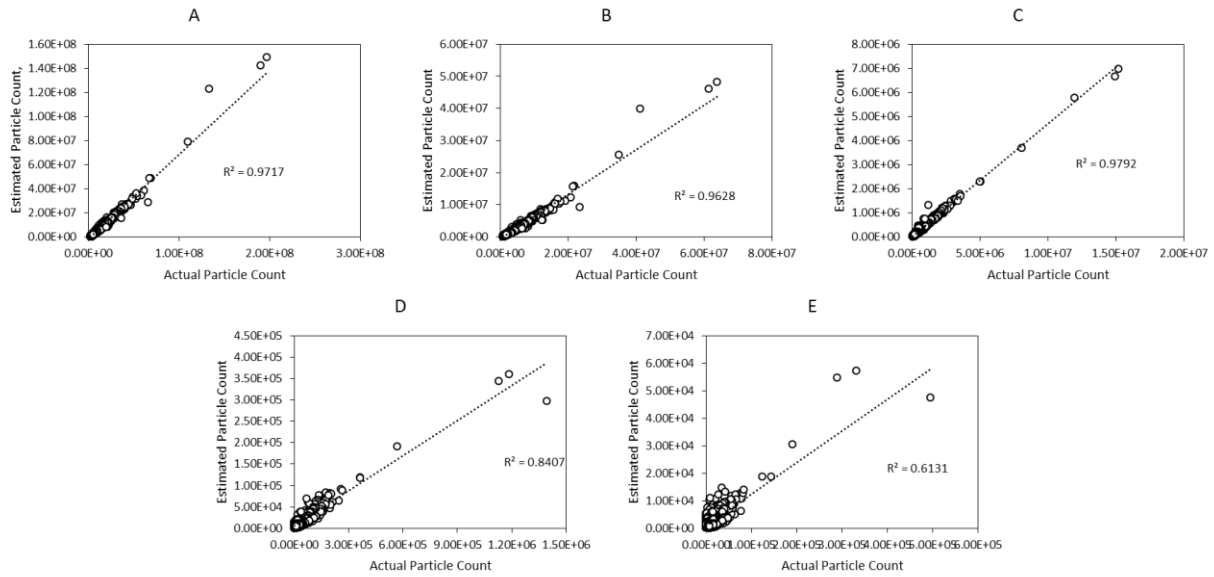
Figure 2: Regression plot between estimated particle distributions against actual particle distribution measured from PA-II

Based on the regression plot, it is observed that the estimated particle distribution agree well with the actual particle distribution with R^2 is more than 0.8 for particle distribution channel A to D and $R^2 > 0.6$ for channel E. This justifies the reliability of the developed PDE model for measuring particle distribution.

IV.   CONCLUSION

APDE model for estimation of particle distribution based on particulate mass concentration was developed in this study. This model was evaluated in a new environment and based on the findings; it was observed that the estimated particle distribution shows excellent correlations with the actual particle distribution from the reference instrument. The estimated Particle count distribution between 0.3μm to 2.50μm (Channel A to D) shows strong positive correlation with the reference data with $R^2 > 0.8$ whereas moderate correlations were observed for estimated Particle count distribution between 5.0μm to 10.0μm (Channel E) with $R^2 > 0.6$.

V.   ACKNOWLEDGEMENT

VI.   REFERENCES

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