EVALUATION OF CONTINUOUS AND FILTER-BASED METHODS FOR MEASURING $PM_{2.5}$ MASS CONCENTRATION IN BANDUNG URBAN AREA

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Abstracts: Assessing the effects of air pollution to public health requires continuous and accurate measurements of particle with aerodynamic diameter < 2,5 μm ($PM_{2,5}$). This study seeks to evaluate sampling performance of samplers from newly established monitoring network, Surface Particulate Matter Network-SPARTAN for $PM_{2,5}$ mass concentration measurements at an urban site in Bandung, Indonesia. Sampling were carried out during January-August 2014 where a filter based sampler, AirPhoton® Filter Sampler, an automated continuous sampler, AirPhoton® Nephelometer, operated in parallel and simultan with the reference instrument, Harvard Impactor. 21 days intercomparison study showed good agreement (R^2=99,4% P-Value=0,000) between $PM_{2,5}$ mass concentration measured by two filter based method, Filter Sampler ($\bar{x}$=31,55 μg/Nm^3) and Harvard Impactor ($\bar{x}$=34,10 μg/Nm^3). Nephelometer backscatter in 532 nm wavelengths (green) resulted hourly estimates of $PM_{2,5}$ mass concentration. Hourly estimates of $PM_{2,5}$ has $\bar{x}$=36,754 μg/Nm^3 and stdev=20,610 μg/Nm^3, which is similar with filter-based measurement result, $\bar{x}$=36,80 μg/Nm^3 and stdev=8,04 μg/Nm^3.

Keywords: fine particulate, urban, nephelometer, filter, impactor

INTRODUCTION

$PM_{2.5}$, particles with aerodynamic diameter less than or equal to 2.5 μm, is one of the main pollutants of the atmosphere. Highest $PM_{2.5}$ pollution commonly found in large cities with high population density (Liu et al., 2009). Long term exposure of $PM_{2.5}$ is a strong indicator of chronic obstructive pulmonary diseaseand cardiorespiratory mortality (Pope, 2000).$PM_{2.5}$ aerosols present a high risk of deposition in the alveoli of lungs and are associated with a greater general health risk than coarse aerosols (Lipmann, 1998 in Fujii *et al.*, 2014).

Former research by Zannaria et al. (2008) about respirable particulates exposure in Bandung concluded that the citizens potentially exposed to 16,56 – 26,86 μg/m^3 $PM_{2.5}$ everyday. This condition meets the ambient national standard, but needs to be considered as early warning for long term $PM_{2.5}$ monitoring needs in Bandung. Increasing tendency of emission load and Bandung topographical condition which is not well ventilated potentially cause increasing health risks due to $PM_{2.5}$ exposure for the population (Zannaria et al.,2008).

Surface Particulate Matter Network-SPARTAN is a newly established global particulate monitoring network consists of automated continuous monitoring using *Nephelometer* and integrated sampling on filters using Filter Sampler. Combinations of these samplers allows to obtain hourly $PM_{2.5}$ mass concentrations estimates (Snider et al., 2013). This study seeks to evaluate Surface Particulate Matter Network-SPARTAN samplers' performance for measuring $PM_{2.5}$ mass concentration in an urban site in Bandung, Indonesia. Previous studies in Halifax (low $PM_{2.5}$), Atlanta (moderate $PM_{2.5}$), and Beijing (high $PM_{2.5}$) resulted that the nephelometer readings were in good agreement with reference instruments at all three sites (R^2>0.80) and Filter Sampler were in good agreement with federal reference method (FRM) instruments with coefficient of variation of R^2=0.96. In Bandung, evaluation conducted by comparing the samplers' performance with a reference instrument, Harvard Impactor, (Marple et al., 1987) which operated in parallel and simultaneously with Filter Sampler and Nephelometer.

RESEARCH METHODOLOGY

Sampling of fine particulate ($PM_{2.5}$) was carried out in the PAU Building (Interuniversity Research Center), Institut Teknologi Bandung Campus, Bandung. Samplers mounted on the open roof of the building, which is at 6°53'16.9"S 107°36'36.0"E and 826 meters above sea level. The location is adjacent to the main road, industrial, incinerator, settlement, trade, shops, traditional markets, and transportation that represent the mixing area of human activity in urban areas.

Sampling of fine particulate matter (PM2.5) was performed using three measurement instruments, namely AirPhoton® Filter Sampler, AirPhoton® Nephelometer (AirPhoton® Combined Sampling Station, AirPhoton® LLC, Baltimore, MD, USA), and Harvard Impactor (MS&T Area Sampler, Air Diagnostics and Engineering, Inc., Harrison, ME,USA). Sampling was performed in two stages as in **Fig 1.**

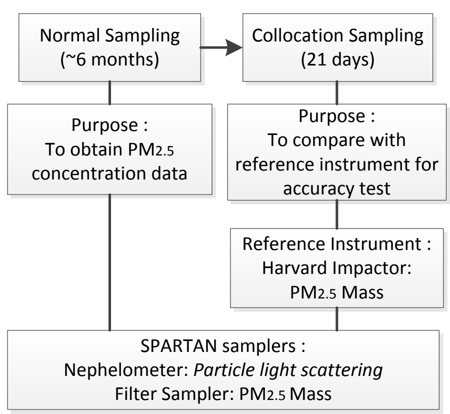

Fig 1. Sampling stages

During Normal Period (Jan 10 – Jun 29, 2014), Nephelometer sampled continuously while Filter Sampler (4 L/m^3)actively sampled 160 minutes/day for 9 days so that a total of 24 hours of sampling per filter was obtained. During Collocation Period (Jul 18 – Aug 20, 2014, all samplers sampled continuously (~24 hours/day), in parallel with reference instrument Harvard Impactor (10 L/m^3).

RESULTS AND DISCUSSIONS

In this section will be explained about the results of evaluating SPARTAN samplers performance for $PM_{2.5}$mass concentration measurements in Bandung urban area.

Filter Sampler Performance Evaluation

Data during Collocation Sampling (21days) will be used to evaluate Filter Sampler sampling performance. $PM_{2.5}$ Filter Sampler compared with $PM_{2.5}$ Harvard Impactor using linearity test method (**Fig2**)

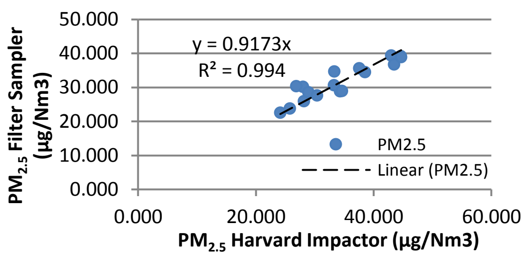

Fig 2. Linearity test for$PM_{2.5}$Filter Sampler

Linearity test results between PM2.5 Filter Sampler (n = 17, =31,55 µg/Nm3) with PM2,5 Harvard Impactor (n = 17, =34,10 µg/Nm3) showed that there is a statistically significant relationship between the two parameters with p-value of 0.000. That is, if the PM2.5 measured by Harvard Impactor increases, then PM2.5 measured by Filter Sampler has the same linear tendency to increase. Low slope of 0.92, indicating that Filter Sampler tends to underestimate Harvard Impactor measurement, which is the true value. This can be caused by Filter Sampler configuration that uses nuclepore filter instead of a cyclone as ~PM2.5 size cut. Harvard Impactor uses a cyclone inlet PM2.5 which is more accurate for size selection. Moreover, coefficient of determination R2 showed a near perfect correlation, 99.08% indicates that the differences between the two filter-based samplers results are not significant. Thus, Filter Sampler is a realiable measurement method to measure PM2.5 mass concentration in Bandung.

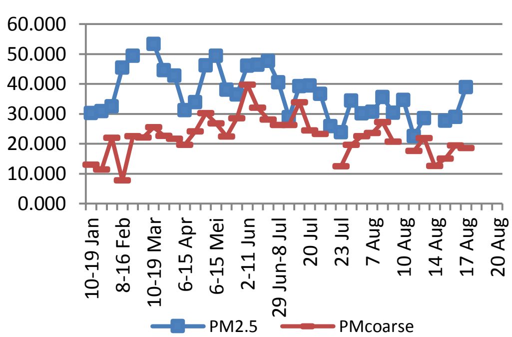

Fig 2. $PM_{2.5}$ ($\mu g/m^3$) Filter Sampler

During this period, the average concentrations of $PM_{2.5}$ was 36.80 μg/Nm^3 while the average for PM_{coarse} 22.45 μg/Nm^3. Thus, the average $PM_{2.5}/PM_{10}$ is 0.629 ($PM_{10} \approx PM_{2.5} + PM_{coarse}$). 24-hour gravimetric filter measurements are the reference method for monitoring $PM_{2.5}$ based on Government Law No. 41 Year 1999, however this method has several limitations such as; high operation cost, high maintenance need, and provide no real time information (Molenar, 2005).Real-time and continuous data are important for evaluating temporal variation of $PM_{2.5}$ exposure to human and creating control emission strategy. In response to the above concerns, the use of nephelometry as a real-time continuous $PM_{2.5}$ aerosol monitoring instrument has emerged to complement filter-based measurements (Molenar, 2005; Radojevic, 2011).In this study, gravimetric mass $PM_{2.5}$ will be combined with Nephelometer *particle light scattering* to create hourly $PM_{2.5}$ estimates in Bandung.

Nephelometer Performance Evaluation

Nephelometers have proven to be capable of making highly accurate, real-time, and continuous measurements of the aerosol scattering coefficient. However, the estimate of aerosol mass by nephelometery has high uncertainties due to natural variability of $PM_{2.5}$ aerosol parameters, ambient humidity, and design configurations (Molenar, 2005; Radojevic, 2011). This constraints made estimation of $PM_{2.5}$ mass by nephelometry must be calibrated with simultaneous gravimetric measurements of the ambient $PM_{2.5}$ to obtain accurate results (Molenar, 2005).

AirPhoton® Nephelometer records*particle light scattering* data continuously at 450 nm (blue), 532 nm (green), and 632 nm (red) wavelengths during the measurement period. Combination of backscatter data and $PM_{2.5}$concentration data per 9 days measured using Filter Sampler can be used to estimate the hourly $PM_{2.5}$ concentration. The formula for estimating $PM_{2.5}$concentration are shown in **Equations 1 and 2** (Snider et al., 2014).

$$\mathrm{b_{sp,dry,1h}} = \frac{\mathrm{b_{sp,1h}\{RH < 80\%\}}}{f_m(RH)} \quad \textbf{(Eq. 1)}$$

$$\mathrm{PM_{2,5,dry,1h}} = PM_{2,5,dry,9d}\frac{\mathrm{b_{sp,dry,1h}}}{b_{sp,dry,9d}} \quad \textbf{(Eq. 2)}$$

Where: $\mathrm{b_{sp,1h}}$= Backscatter averages for 1 hour; $\mathrm{b_{sp,9d}}$= Backscatter average for 9 days; f_m(RH)= Higroscopic mass correction factor, correction for water uptakein aerosol = 1 + 0,2 RH/(100 – RH); $\mathrm{PM_{2,5,dry,1h}}$= Hourly $PM_{2.5}$ mass concentration estimates; $PM_{2,5,dry,9d}$= 9-day filter result for $PM_{2.5}$ mass concentration.

Nephelometer $PM_{2.5}$ estimatescompared with Harvard Impactor $PM_{2.5}$gravimetricto evaluate Nephelometer performance (**Fig 3**).

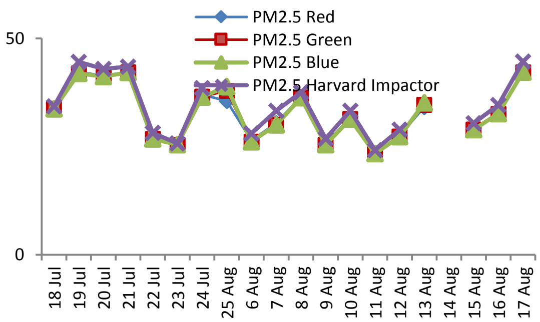

Fig 3. Comparison of $PM_{2.5}$ Nephelometer (RGB) and Harvard Impactor (μg/m^3)

Results showed that there are no significant differences between estimates by the three wavelengths, which are 32, 765 μg/m^3 (red), 32, 574 μg/m^3 (blue), dan 32,561 μg/m^3 (green).Linearity test between Harvard Impactor $PM_{2.5}$ and Nephelometer $PM_{2.5}$ resulted R^2=0.9923 for red scatter, R^2=0.9902 for green scatter, and R^2=0.9897 for blue scatter. Therefore, nephelometer scatter in all wavelengths could be used for estimating hourly $PM_{2.5}$ estimates in Bandung.

Hourly $PM_{2,5}$Concentration Estimates

Strong correlation (R^2=0.88) found between $PM_{2.5}$ estimates using green scatter with $PM_{2.5}$ mass measured by Beta Attenuation Monitor (BAM) in Beijing during February 24 – March 29, 2013. However, the usage of red scattering and blue scattering for estimating $PM_{2.5}$ still needs further investigations (Snider *et al.*, 2013). Because of those considerations, estimation of horly $PM_{2.5}$ in this study performed using green scattering (532 nm) data. Hourly $PM_{2.5}$ estimates during January – August 2014 showed in **Fig 4.**

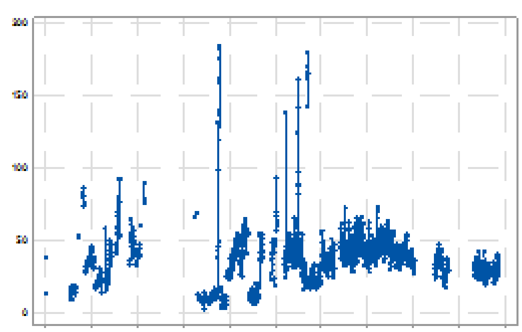

Fig 4. Hourly $PM_{2.5}$ mass concentration estimates (μg/m^3), 10 Jan 14 09:00 – 21 Aug 14 09:00

Average of hourly $PM_{2.5}$ concentrations estimates on the entire measurement period is

36.547 μg/Nm^3 with standard deviation of 20.610 μg/Nm3. While, the average concentrations of $PM_{2.5}$ from Filter Sampler are 36.80 μg/Nm^3 with standard deviation of 8.04 μg/Nm$^{3.}$ This insignificantly different average values shows that the hourly $PM_{2.5}$ estimates represents filter based measurement well, while larger standard deviation showed that the estimates successfully explained periods of high and low $PM_{2.5}$ concentrations well. This data can be used for assessment of health risk associated with air pollution in Bandung. Combination of these data with data from another SPARTAN locations can be used to assess impact of $PM_{2.5}$ pollution for global health applications.

Another study at an adjacent location to this study, precisely in the rooftop of Nuclear Technology Center for Materials and Radiometry building (6.91^{o}S 107.60^{o}E, 630 mdpl) in 2002 – 2011 using a Gent stacked filter unit for 24 hour, 2 measurements per week, and at flowrate 15-18 lpm (Santoso *et al.,* 2008; Santoso *et al.*, 2012; Santoso *et al.,* 2013). Results showed that yearly averagees of $PM_{2.5}$ mass concentration = 14,0 μg/m^3 (2002-2004), 19.0 μg/m^3 (2005), 20,3 μg/m^3 (2006), 20,6 μg/m^3 (2007), and 16,50 μg/m^3 (2011). The study and this study indicates that although $PM_{2.5}$ concentration still meets national quality standards, air quality tends to deteriorate from year to year in the urban area of Bandung. Air quality deterioration is associated with increasing tendency of emission load and Bandung topographical condition that are not well ventilated. This condition could potentially increase the health risk from exposure to $PM_{2.5}$ to the population (Zannaria, et al., 2008).

Research by Lestari and Mauliadi (2009) during rainy season of September 2005 – 2006 and dry season of Maret 2005 – Juli 2007 in Tegalega area, Kota Bandung which represents urban area with mixing activities showed average of $PM_{2,5}$ 30 μg/m^3 in rainy season and 48 μg/m^3 in dry season. Sampling performed using *Dichotomous Sampler* and *Minivol* in 4 meters height from ground. Emission sources identified during the rainy season in the study are diesel vehicles (17%), $(NH_4)_2SO_4$ (14%), biomass burning (13%), NH_4NO_3 (12%), soil dust (10%), motorcycles (9%), volcanic dust (6%), and cars (9%), while during dry season are $(NH_4)_2SO_4$ (25%), electroplating industries(24%), biomass burning (16%), aged sea salt (13%), diesel vehicles (12%), motorcycles (7%), and solar vehicles (3%) (Lestari and Mauliadi, 2009). Moreover, further study is needed to determine seasonal and diurnal variability based on $PM_{2.5}$ mass concentration data determined in this study in relations with human activities and meteorological conditions.

CONCLUSIONS

This study seeks to evaluate sampling performance of samplers from newly established monitoring network, Surface Particulate Matter Network-SPARTAN for $PM_{2.5}$ mass concentration measurements at an urban site in Bandung, Indonesia. Intercomparison study with reference instrument Harvard Impactor showed that AirPhoton® Filter Sampler and AirPhoton® Nephelometer was a reliable combination of $PM_{2.5}$ measurement that is applicable in Bandung urban area for long term monitoring. Further study shall investigate any seasonal and diurnal pattern in the hourly $PM_{2.5}$ data and its relationship with human activities and meteorological conditions.

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