Studies on measurement of $PM_{2.5}$ and PM_{10} employing online method: A case of coal fired boiler stack

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Abstract

Deterioration of ambient air quality is one of the major challenges faced by human kind across the globe and release of particulate matter (PM) from industrial sources is believed to be prime contributor for release of PM. The present study focuses on validation of Online Laser Scattering (OLS) method with USEPA 201a method to estimate $PM_{2.5}$ and PM_{10} concentration released from stationary sources.

The present study emphasizes on to establish ratios of $PM_{2.5}/PM$ and PM_{10}/PM in stationary sources to predict emission of $PM_{2.5}$ and PM_{10} simply by measurement of PM through stationary sources. Finally, the research demonstrates good correlation existing in the ratios which can be further utilized to estimate $PM_{2.5}$ and PM_{10}.

Keywords: Stationary sources, air pollution, online measuement.

Introduction

Particulate matter (PM) has been recognized as one of the utmost life-threatening environmental risks worldwide due to industrial growth and expansion[1,2]. Release of PM from industrial sources deteriorates not only ambient air quality but also leads to unhealthy living condition and adversely impacts human health. Particulate matter comes in a wide range of sizes which are originated from numerous dissimilar stationary and mobile sources as well as natural source. [3,4]. Further Dim et al[3] have reported that 75% of the total global dust emissions are of natural origin, while 25% are related to anthropogenic emissions. It is also reported by Fuzzi et al[5] that 25% of urban ambient air $PM_{2.5}$ is contributed by traffic, 15% by industrial activities, 20% by domestic fuel burning, 22% from unspecified sources of human origin and 18% from natural dust such as desert dust and salt.

Exposure to fine PM has been resulting in ill health and death due to respiratory, cardiovascular and cerebrovascular diseases, stroke, irritation of airways, difficult berthing, asthama and decreased lung function lung cancer, reproductive issues and premature death[1,5–7]. Particulate matter is not only responsible for the visibility reduction, but it can also cause damage to materials and vegetation depending on its characteristics.[3,5,8,9]. As per Indian National Ambient Air Quality Standards, limits for $PM_{2.5}$ [24 h (60 $\mu g/m^3$) and annual (40 $\mu g/m^3$)] and PM10 [24 h (100 $\mu g/m^3$) and annual (60 $\mu g/m^3$)], are much higher than the WHO Air Quality Guidelines as well as standards in the USA and Europe[1].

Furthermore, there is a lack of comprehensive information related to the factor required to calculate $PM_{2.5}$ and PM_{10} concentration from known PM concentration releasing through stack to estimate its impacts in impact assessment study. Therefore, it is very essential to study the particulate matter quantities of various particle size which are emitted from the stationary sources to restrict impact of $PM_{2.5}$ and PM_{10}.

Considering the above issues and gaps, the objective of present study is to evaluate $PM_{2.5}/PM$ and PM_{10}/PM ratio to apply in environmental impact assessment study to minimize health and environmental impact of $PM_{2.5}$ and PM_{10} releasing through stationary sources. Thus, the present investigation was carried out in local company having coal fired boiler installed with air pollution control equipment i.e. multicyclone followed by electrostatic precipitator. The measurement of $PM_{2.5}$ and PM_{10} was carried out by OLS and USEPA 201a method to study the performance of online instrument for establishing relationship of PM with $PM_{2.5}$ and PM_{10} releasing from coal fire boiler.

Materials and Methods

Present study to measure $PM_{2.5}$ and PM_{10} released from a stack was carried out in industry A (name is not disclosed due to statutory reasons) located in Vapi Industrial Area, Vapi. For experiment purpose, samples were taken from 10 tonnes per hour (TPH) Fluidized Bed Combustion (FBC) type boiler. Imported coal having average ash content of 6% was used as a fuel which is fed continuously using feed controller. Coal feed rate was varied to 240, 260 and 280 kg/h. Total 500 mL sample volume has been collected to measure concentration of $PM_{2.5}$, PM_{10} and PM using USEPA 201a and OLS method[10].

For entire research purpose, particulate matter was measured using USEPA 17 method[11] and $PM_{2.5}$ and PM_{10} were measured employing USEPA 201a method [12] and OLS method. Temperature and velocity of the flue gas were measured using thermocouple and velocity kit to decide nozzle diameter. The pressure drop of flue gases in stack in mm H_2O was measured using pitot tube. Samples were taken through traverse points at isokinetic conditions using vacuum pump.

To measure particulate matter using USEPA 17 method, standard glass fibre thimbles were used. To measure $PM_{2.5}$

using USEPA 201a method, $PM_{2.5}$ cyclone was attached after nozzle in sampling train. Only $PM_{2.5}$ particles will come out from cyclone and will be deposited on standard filter paper. Weight of filter paper will give concentration of $PM_{2.5}$. Similarly, PM_{10} can be measured by replacing $PM_{2.5}$ cyclone with PM_{10} cyclone in sampling train.

The OLS method works on the principle of light scattering and subsequently analyses the particle size. The mechanism of laser scattering adopts laser transmission method to measure the $PM_{2.5}$ and PM_{10} concentration. The diode laser acts as a lamp. The laser reflected light is detected by the detector and forms referenced signals. Transmission light shines to the reflecting material through the measured environment with particulate matter. The reflected light is detected by detector and forms measuring signals which is recorded in data receiver.

In OLS method, sampling was taken as per USEPA17 method. Vacuum pump outlet was attached to inlet of heat exchanger to reduce heat of flue gases to meet instrument requirement. The velocity of stack gas was maintained as per instrument requirement using rotameter. Flue gases passed through the OLS instrument to evaluate $PM_{2.5}$ and PM_{10} and send real time data to data receiver.

All the samples were carried out at identical conditions by keeping all other variables constant. Stack temperature was 80^{o}C, average pressure drop was 2 mm H_2O, velocity 33.7 m/s, ambient temperature is 32^{o}C.

Figure 1 shows schematic and actual arrangement of laser scattering analyser to measure concentration of $PM_{2.5}$ and PM_{10}.

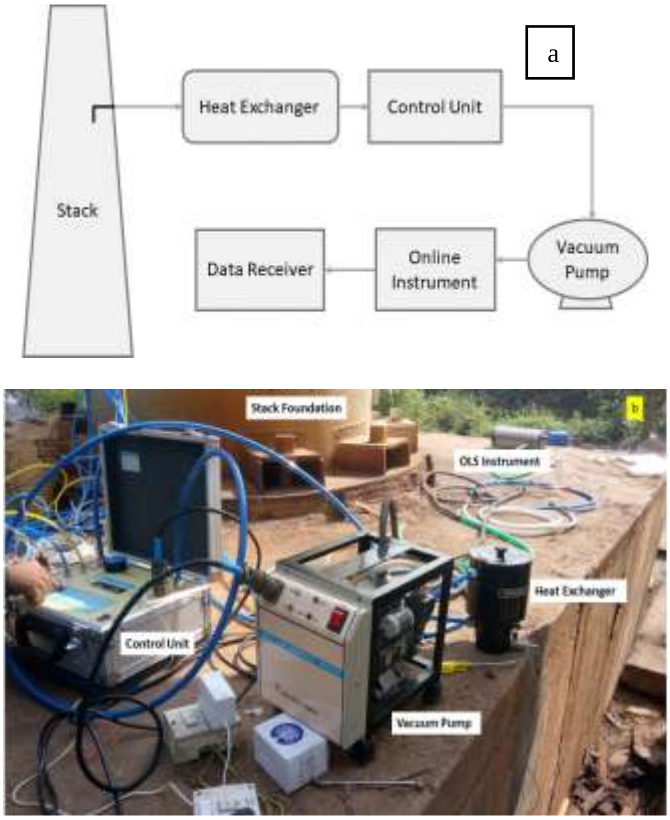


Figure 1: Experimental set – up with OLS analyzer to measure PM2.5 and PM10 in industry (a) schematic diagram (b) actual arrangement on site

Table 1
$PM_{2.5}$ and PM_{10} concentration (mg/m^3) from USEPA 201a and OLS method

Reading	USEPA 201a		OLS (average reading)	
	$PM_{2.5}$	PM_{10}	$PM_{2.5}$	PM_{10}
1	8.32	10.46	12.45	14.41
2	8.3	10.56	12.46	14.42
3	8.43	10.58	12.51	14.45
4	8.42	10.62	12.52	14.43
5	8.71	11.38	12.92	14.49
6	8.78	11.36	12.91	14.51

Results and Discussion

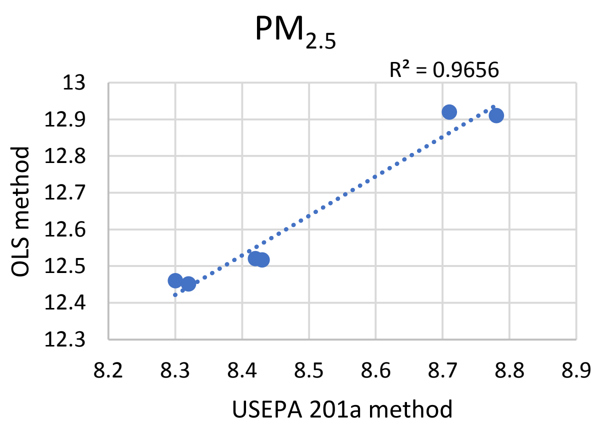
The studies were carried out in industry and data collected as per the protocol. Table 1 represents the concentration of $PM_{2.5}$ and PM_{10} collected from 10 TPH FBC type boiler stack having coal feed rate of 250 kg/hr. The concentration of $PM_{2.5}$ ranges from 8.3 to 8.78 with the average 8.49 and the concentration of PM_{10} ranges from 10.46 to 11.38 with the average 10.82 as per USEPA 201a method while in the OLS method, $PM_{2.5}$ concentration ranges from 12.45 to 12.92 with the average 12.62 and concentration of PM_{10} ranges from 14.41 to 14.51 with the average concentration of 14.45 mg/m^3.

The percentage standard deviation in USEPA 201a method for $PM_{2.5}$ is 0.20 while in OLS method it is 0.42. Similarly, percentage standard deviation in USEPA 201a method for PM_{10} is 0.22 while in OLS method it is 0.04. The percentage variation in difference in OLS method as compared to USEPA 201a method or $PM_{2.5}$ is 0.48 whereas for PM10 it is 0.33 which remains almost same throughout number of samples taken throughout this study. The correction factor should be established to correlate OLS method with the USEPA 201a method. Figure 2 depicts a typical data sets of $PM_{2.5}$ and PM_{10} measured by USEPA 201a and OLS method. It shows that OLS instrument has a linear correlation with the USEPA 201a method and the R^2 value for $PM_{2.5}$ and PM_{10} is 0.96 and 0.90 respectively and presented in table 2.

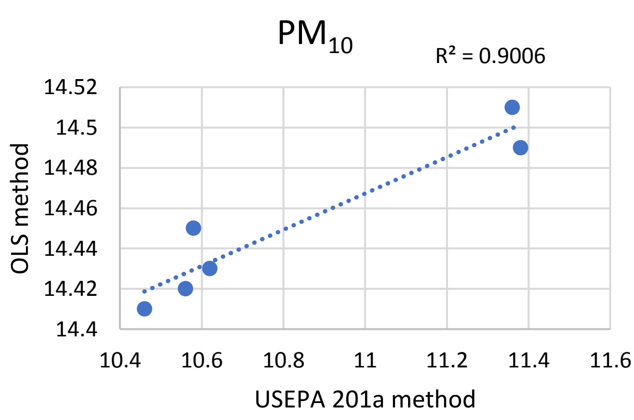
Effect of coal feed rate on $PM_{2.5}$/PM and PM_{10}/PM ratio: As coal feed rate increases, the amount of PM concentration increases along with $PM_{2.5}$ and PM_{10}. Figure 3 depicts that the ratios of $PM_{2.5}$/PM and PM_{10}/PM clearly indicates that by changing coal feed rate from 240 to 280 kg/hr, the ratio of $PM_{2.5}$/PM and PM_{10}/PM remains almost constant. The average ratio for $PM_{2.5}$/PM and PM_{10}/PM is 0.1211and 0.1531 respectively. Throughout the studies all other variables were kept constant.

Table 2
R^2 values for $PM_{2.5}$ and PM_{10} measured by OLS Instrument and USEPA 201a

Parameter	R^2
PM_{10}	0.90
$PM_{2.5}$	0.96

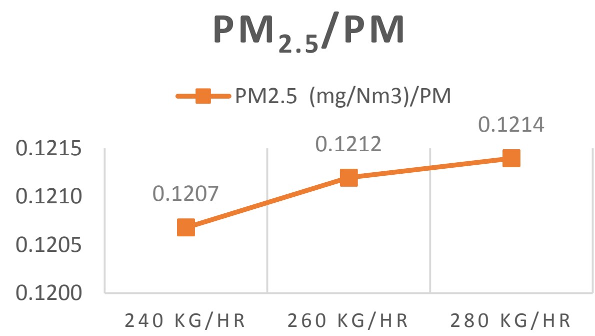


(a)

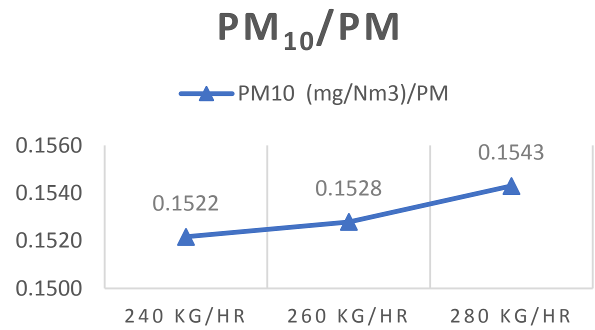


(b)

Figure 2: Correlation of data generated by OLS and USEPA 201a method for (a) $PM_{2.5}$ and (b) PM_{10}

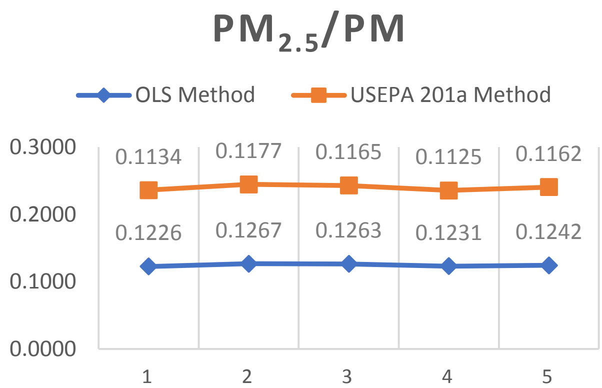


(a)

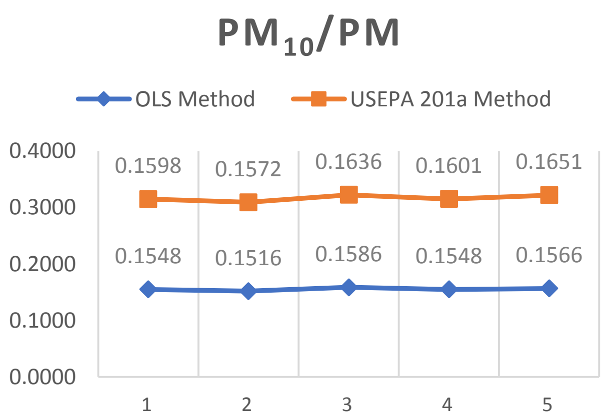


(b)

Figure 3: $PM_{2.5}$/PM and PM_{10}/PM by OLS and USEPA 201a method for different coal feed rate



(a)



(b)

Figure 4: $PM_{2.5}$/PM and PM_{10}/PM by OLS and USEPA 201a method

Measurement of $PM_{2.5}$/PM and PM_{10}/PM ratio: $PM_{2.5}$/PM and PM_{10}/PM are measured using OLS and USEPA 201a method emitted through stationary source having coal feed rate 240 kg/hr Figure 4 shows that the average ratio of $PM_{2.5}$/PM using USEPA 201a method is 0.1153 and OLS method is 0.1246, similarly the average ratio of PM_{10}/PM using USEPA 201a method is 0.1612 and OLS method is 0.1553. At constant coal feed rate, $PM_{2.5}$/PM and PM_{10}/PM remain almost constant. The ratio of $PM_{2.5}$/PM and PM_{10}/PM may be applicable for measurement of one-time concentration of $PM_{2.5}$ and PM_{10} at specific stationary source using online method to establish $PM_{2.5}$/PM and PM_{10}/PM ratios.

Afterwards, $PM_{2.5}$ and PM_{10} emission can be estimated using these ratios by taking existing maximum permissible limit of particulate matter through stationary sources prescribed by statutory body to identi its health and environmental impacts. Thus, this research establishes online method for analysis of $PM_{2.5}$ and PM_{10}, which provides comparable results with USEPA method. In addition, the research also provides simple way to estimate $PM_{2.5}$ and PM_{10} by measuring only PM and afterwards through well-established ratios of $PM_{2.5}$ and PM_{10} with PM, the values of $PM_{2.5}$ and PM_{10} can be calculated out. The quick estimation of $PM_{2.5}$ and PM_{10} concentration release from stationary sources may be widely used in air dispersion modeling and also in assessment of environmental impact due to $PM_{2.5}$ and PM_{10}.

Conclusion

Estimation of $PM_{2.5}$ and PM_{10} through stationary sources is crucial due to its health and environmental impacts. The measurement of $PM_{2.5}$ and PM_{10} by OLS method shows the relative increment with increase in coal feed rate. Variation in concentration of $PM_{2.5}$ and PM_{10} remains constant with varied coal feed rate. Further it is concluded that ratios of $PM_{2.5}$/PM and PM_{10}/PM measured using OLS method and USEPA 201a method are almost similar. There is no major effect of coal feed rate on $PM_{2.5}$/PM and PM_{10}/PM ratio is observed.

Further it is concluded from the present study that contribution of $PM_{2.5}$ and PM_{10} in particulate matter is 12.46% and 15.53% respectively. The quick and simple estimation of $PM_{2.5}$ and PM_{10} concentration release from stationary sources may be useful for air dispersion modeling and also in assessment of environmental impact due to $PM_{2.5}$ and PM_{10}.

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