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ABSTRACT

Black Carbon (BC) in $PM_{2.5}$ and PM_{10} concentrations in Ashaiman, a semi-urban area of Ghana, were determined in 2008 using IVL $PM_{2.5}$ and PM_{10} particle samplers. The aerosols were sampled on Teflon filters for three months, and the particulate mass $PM_{2.5}$ and PM_{10} determined by gravimetrical method. Aerosol filters were analyzed to determine BC concentration levels using the black smoke method. $PM_{2.5}$ mass concentrations determined averaged $23.26\mu g/m^3$ ($3.85 - 46.43 \ \mu g/m^3$) and that of PM_{10} was $96.56\mu g/m^3$ ($37.10 - 293.06 \ \mu g/m^3$). For fine particulates ($PM_{2.5}$), the contribution of BC have been found to be about 18% of the total mass, while for particulate matter PM_{10} , it has been found to be about 4%, its averaged $2.83\mu g/m^3$ ($1.67-4.89\mu g/m^3$) for $PM_{2.5}$ and $3.98\mu g/m^3$ ($1.99-12.44\mu g/m^3$) for PM_{10} . The results were compared with some literature values and World Health Organization guideline values. The mean 24-h BC values for the particulate mass varied daily and shows that the semi-urban background during the period, not only involved combustion activities which are largely responsible for the $PM_{2.5}$ particulate matter but also involved in other man-made or natural activities that resulted in the high value of PM_{10} .

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Introduction

Airborne particulate matter (PM) are normally sampled according to their sizes measured in terms the aerodynamic diameter. PM_{10} or coarse PM refers to particles that are 10 µm in diameter or less. $PM_{2.5}$, or fine PM, refers to particles that are 2.5 µm in diameter or less.

Particulate black carbon is one of the most important components of atmospheric aerosol. As a by-product of incomplete combustion, it has long been one of the most elusive aerosol species of atmospheric pollution. Black carbon (BC) demands high quality measurements and standards, because it is usually concentrated in the fine (inhalable) size class and typically constitutes a significant, sometimes dominated fraction of the total fine particulate mass. It can affect regional and global climate through absorbing incoming and outgoing radiation and is also understood to have a major negative effect on human health. The exact impacts are however very difficult to predict, owing in part to processes in the atmosphere that can alter their properties and lifecycle through chemically coating the particles. There are large uncertainties associated with emissions of BC to the atmosphere, its aging during atmospheric transportation, and its removal by precipitation (Bond et al., 2004; Riemer et al., 2004; Hoelzemann et al., 2004; Generoso et al., 2003; Khalizov et al., 2009). All these uncertainties propagate directly into global model simulations (Stier et al., 2007; Koch et al., 2010; Bauer et al., 2010; Vignati et al., 2010). For a better understanding of the transportation, removal and climatic impacts of atmospheric BC, accurate and up-to-date knowledge of its global distribution is clearly needed.

Developing countries like Ghana, little information on the concentration levels and temporal variability of BC is available. Even data on concentrations as well as characteristics of particulate matter are almost non-existent in developing countries most of which are in the Southern Hemisphere. For instance, there is almost no routine monitoring of aerosol data in Africa except for South Africa, Egypt and Tunisia (Landsberger and Biegalski, 1995; Kent *et al.*, 1998). Such data would be of great value when investigating the properties and concentrations of BC particles in order to evaluate the effects on heath, climate and when evaluating atmospheric models that simulate the long range atmospheric transport of BC.

The lack of ambient monitoring data for particulate matter in these developing countries severely hinders the ability to describe temporal and spatial patterns of concentrations, in Ghana, the collaboration between the US Environmental Protection Agency (US-EPA) and the United Nations Environmental Program (UNEP) in 2005 led to the development of air monitoring networks in Accra controlled by Environmental Protection Agency (EPA) of Ghana. Most of the activities, which are not on regular and sustained basis are designed to measure total suspended particulates not particulate black carbon. Ashaiman, a semi-urban area of Ghana with the highest population growth rate in Ghana of about 4.6% (GSS, 2002), is characterized by a lot of open burning, household wood and charcoal burning and vehicular traffic. As a result, occasional blackening of the surrounding air and reduced visibility are observed in some areas. Cases of choking smells and irritating eyes have also been observed and reported by inhabitants. Ashaiman is located within Tema municipalities, the industrial city of Ghana.

There are several methods of estimating elemental carbon concentration. One of them is by using a smoke stain reflectometer. Particulate matter (PM) samples collected on filter media were analysed gravimetrically to determine the mass and subsequently black carbon concentration levels determined by an EEL Smoke Stain Reflectometer (Model 43D, Diffusion Systems Ltd, London). It is possible to estimate Elemental (EC) or Black Carbon (BC) concentrations in the atmosphere as Black Smoke (BS) by simply measuring light absorption or reflectance as PM collected on filter media. The darkness of the particulate sample is consequently an indication of the amount of EC on the filter and is often referred to as Black Smoke (BS). Analytical methods commonly used to measure elemental carbon (e.g. thermal optical analysis) is expensive and destructive to the sample material, hence the choice of the Reflectometric method. Several studies have reported that black smoke, derived from absorbance coefficients, is well correlated with the concentration of elemental carbon or soot and can be recommended as a valid and cheap indicator in studies on combustion-related air pollution and health (Cyrys *et al.*, 2003; Götschi *et al.*, 2002; Janssen *et al.*, 2001; Kinney *et al.*, 2000).

The main objective of this project was to determine the fractions of BC in the fine, $PM_{2.5}$ and coarse, PM_{10} particles within Ashaiman, a sprawling "urban slum" in the Greater Accra Region of Ghana. This will serve as the basis for further research on the concentration levels and temporal variability of BC.

Experimental Work

Sampling site and sampling equipments: A central outdoor monitoring site which represents the exposure in the population was mounted at a site about 1.1 km from the central business centre of Ashaiman. The aerosol particles sampling was carried out for 90 days between February and May, 2008. The possible emission sources in the area are mainly domestic or residential burning and the major streets near and within the Ashaiman Township. The GENT and ANDERSEN pumps connected to IVL PM_{2.5} and PM₁₀ particle size separator were used to collect aerosol samples on Teflon filters. The compact vacuum pumps are controlled by a timer. In both cases the PM fraction for particles above the desired size range, determined in terms of aerodynamic diameter, were collected on impactor plates impregnated with Apiezon grease, which are cleaned and saturated on occasionally basis in order to prevent particle bounce.

Teflon filters conditioned for five days before weighing were used. The pore size of Teflon used for the PM₁₀ fraction has a pore size of 2.0 μ m and 47 mm in diameter. That of the PM_{2.5} fraction is 0.2 μ m for the pore size and 25 mm in diameter. The sampling in this work was done for approximately 24 h and at a flow rate of approximately 17.0 l/min.

Gravimetric analysis: The filters were weighed before and after sampling using a Sartorius MC-5 micro-gramme sensitive balance in a temperature- and relative humidity controlled environment. Gravimetric analysis was performed to determine the mass concentration of the sample aerosol. It is very important to determine the particulate mass concentration because all other analytical measurements will necessarily depend on the mass deposited. The total volume of air sampled is determined from the total volumetric flow rate (l/min) and sampling time in seconds. The concentration of PM₁₀, PM_{2.5} in the ambient air is computed as total mass of collected particles divided by the volume of air sampled in actual conditions. The concentrations are expressed in micrograms per actual cubic meter (μ g/m3).

The equation governing the gravimetric analysis is given below:

$$C_{PM} = \frac{m}{V}$$
⁽¹⁾

where,

C_{PM} = particulate Matter Mass Concentration

 $m=net\ mass\ of\ the\ particulate\ matter\ collected\ on\ the\ sample\ filter$

V = the volume of air sampled

Measurement of reflectance: After the gravimetrical analysis, the filters were examined for black smoke by measuring the reflectance using an EEL 43D Smoke Stain Reflectometer (Diffusion Systems Ltd., London, UK). Each filter was examined five times and the average value was used in the calculations.

A light source shines its light on the filters, and the reflected light is measured by photocells located in a black housing. The reflector reading is obtained directly from the DS 29 universal digital readout. Reflectance readings (output voltages readings) were obtained for the aerosol or sample filters, totally black filter and totally white filter.

After every series of five sampled filters reading, the calibration parameters were re-set to 8.0 for a white filter and 0.4 for a totally black filter.

Analysis of black smoke: The Black Carbon (BC) in the sample filters were from the three output voltages (i.e., voltages from the aerosol filters, totally black filter and totally white filter) obtained by using EEL smoke stain reflectometer. The output voltages obtained from the smoke stain reflectometer measurement are converted to a measure of blackness. The blackness is essentially determined by the use of Lambert-Beer's law (Gagel, 1996). Provided that thin layers of aerosol particles are collected on the filter (a single dust layer), the equation relating the output voltages to the black smoke number as stated is described below can be used to calculate for the black smoke number or blackness.

The operating principle of the Reflectometer used in this work is known as the "black smoke method" (Gagel, 1996). The measured reflectance or the output voltage obtained from the aerosol filter is converted to a measure of blackness known as "black smoke number", RZ which is determined from the three output voltage obtained, i.e. from the aerosol filter to be evaluated, the totally white filter and the totally black filter. The equation relating the output voltages to the black smoke number is:

$$RZ = RZmax \left(U_{RZ0} - U_{RZ max} \right) \left(U_{RZ0} - U_{RZ max} \right)$$
(2)

where

 U_{RZ0} = Output voltage with blank (white) filter (which is set to 8.0 V according to the instructions manual)

 U_{RZmax} = Output voltage with totally black filter (set to 0.4V) U_{RZ} = Output voltage with sample to be evaluated

The black smoke number, RZ, together with the measured volume of air sampled and the calibration constant are used to calculate the ambient concentration of black smoke using Lambert - Beer's law given below:

$$C_{R} = -\left(\frac{RM_{1}}{V}\right) ln\left(1 - \frac{(RZ - RZ_{0})}{\Box}(kRZmax)\right)$$
(3)

where,

 C_R = the black carbon concentration

V = the sampled air volume

 RM_1 = the black carbon mass in a single dust layer on the filter RZ_0 = the black smoke number for a white (blank) filter RZ = the black smoke number for the actual filter RZmax = the black smoke number for a black filter K = Calibration constant

Finally, CR is adjusted by a multiplication constant (the ratio of the filter area to the black spot area) to get the total BC concentration.

Results and discussion

PM_{2.5}, PM₁₀ and BC Mass Concentrations (µg/m³)

Table 1 gives a summary of the mean concentrations of $PM_{2.5}$, and PM_{10} , their respective BC fractions measured at Ashaiman during the period of study. The maximum and the minimum values are also provided in the table to give an indication to how widely they varied from day to day.

Property	Maximum	Minimum	Mean	Standard
				Deviation
$PM_{2.5}/\mu gm^{-3}$	46.43	3.85	23.26	12.66
$PM_{10}/\mu gm^{-3}$	293.06	37.10	96.56	49.59
BC in PM _{2.5} /	4.89	1.67	2.83	0.75
µgm⁻³				
BC in PM ₁₀ /	12.44	1.99	3.98	1.81
µgm ⁻³				
BC/PM 2.5	0.63	0.06	0.18	0.15
BC/PM ₁₀	0.13	0.01	0.05	0.03

Table 1 : Mean values of PM2.5, PM10 and Black Carbon

The BC in $PM_{2.5}$ and PM_{10} collected on the filters varied from day to day. To better visualize the trends in the 24 hour daily variations in BC, the complete data set was plotted and represented in figure 1 and 2. The calculated fraction of Black Carbon concentration levels in PM_{2.5} and PM₁₀ indicates that, PM_{25} is dominated by black carbon (figure 3). For fine particulates (PM_{2,5}), the contribution of Black Carbon (BC) have been found to be about 18% of the total mass, while for particulate matter PM₁₀, it has been found to be about 4%. It followed from these values that black carbon constitutes a greater fraction if not dominated portion of PM_{2.5}. BC is a tracer of primary anthropogenic emissions, and its variability reflects changes in source strengths, long-range transport, and atmospheric mixing characteristics (Viidanoja et al., 2002). Fine fraction contains most of the respirable particulate matter and mostly generated by combustion activities



Figure 2: PM₁₀ Black Carbon daily variations





The results shows that semi-urban background during the period of study, not only involved combustion activities which are largely responsible for the $PM_{2.5}$ particulate matter but also involved in other man-made or natural activities that resulted in the high value of PM_{10} .

From the World Health Organization recently documented air quality guidelines for PM_{10} and $PM_{2.5}$ as well as interim target concentrations for use by developing countries in measuring progress towards the guideline concentrations (WHO, 2006). The PM_{10} interim targets for annual average concentrations start at $70\mu g/m^3$ and extend down to the $20\mu g/m^3$ guideline and for $PM_{2.5}$, the first annual target is $35\mu g/m^3$, and the guideline is $10\mu g/m^3$. Clearly, the average PM₁₀ value for this study exceeded WHO guideline and that of PM2.5 is very close to WHO limit value. Aboh and Ofosu (2005/2006), reported a daily mean PM2.5 and PM10 concentrations of 4.3 and 59.7µg/m3 at a site located in Kwabenya near Accra, Ghana (within the same region) during 2005/06 harmattan. These values are much lower than the results from Ashaiman, the difference in the values from Ashaiman could be due to the fact that Ashaiman is characterised by local pollution such as open burning, domestic wood and charcoal burning, and vehicular traffics. In addition, the status of the road network within Ashaiman, where a lot of roads are unpaved play a significant role in the entrainment of dust, which could be attributed to the high PM₁₀ fraction. Construction of roads and other infrastructure, which are common in this area, also played a major role in the coarse fraction. Ashaiman shared a boundary with Tema, the industrial city of Ghana.

Conclusion

This study has quantified the BC concentrations in $\rm PM_{2.5}$ and $\rm PM_{10}$ for a Semi-urban site in Ghana. The $\rm PM_{2.5}$ mass concentrations determined averaged 23.26µg/m³ (3.85 - 46.43 µg/m³) and that of $\rm PM_{10}$ was 96.56µg/m³ (37.10 - 293.06 µg/m³). For fine particulates ($\rm PM_{2.5}$), the contribution of Black Carbon (BC) have been found to be about 18% of the total mass, while for particulate matter $\rm PM_{10}$, it has been found to be about 4% , its averaged 2.83µg/m³ (1.67-4.89µg/m³) for $\rm PM_{2.5}$ and 3.98µ g/m³ (1.99-12.44µg/m³) for PM₁₀.

The mean 24-h BC values for the particulate mass varied daily and recorded some high values for both $PM_{2.5}$ and PM_{10} . This could be attributed to the heavy industrial pollution from Tema, the industrial city of Ghana. Ashaiman shared a boundary with Tema. Also, these high values suggest instances of high local pollution such as open burning, domestic wood and charcoal burning and local traffic.

The semi-urban background aerosol of Ashaiman, is not only largely made up of combustion generated carbonaceous particles but particles from natural activities that also resulted in high PM_{10} values. More work needs to be done in particulate matter measurement in Ghana, since the mean value obtained is very close to WHO interim limit value and Ghana EPA is yet to set a guideline value for $PM_{2.5}$.

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