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Particulate Matter and Black Carbon Concentration Levels in Ashaiman, a Semi-Urban Area of Ghana, 2008

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Abstract: Particulate matter and black carbon concentration levels in Ashaiman, a semi-urban area of Ghana was assessed. Using IVL $PM_{2.5}$ and PM_{10} particle samplers, airborne particulate matter was sampled on Teflon filters for a period of three months. In addition to determination of particulate mass in the two fractions by gravimetrical method, aerosol filters were analyzed to determine Black Carbon (BC) concentration levels using the black smoke method. BC fractions in fine and coarse, together with $PM_{2.5}$ to PM_{10} ratio were determined. $PM_{2.5}$ 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 $\mu g/m^3$). The results were compared with some literature values and World Health Organization guideline values. The values obtained for $PM_{2.5}$ to PM_{10} ratio and for $PM_{10-2.5}$ concentrations, suggest that, the semi-urban background aerosol is not only largely made up of combustion generated carbonaceous particles but also particulate matter emissions from natural activities.

Key words: Airborne particulate matter, ashaiman, black carbon, black smoke method, gravimetric method, particle samplers

INTRODUCTION

Air, an invisible gas made up of a mixture of mainly nitrogen and oxygen is one of the fundamental basics of life for humans, animals and plants. The quality of the air we breathe is therefore essential for our health. It is becoming increasingly important to keep it clean for the future, as lots of contaminants such as smoke, dust and gases are discharged into the atmosphere. Air pollution occurs when contaminants are released into the air, in amounts that could be harmful to people and animals, or could damage plants.

Airborne particulate matter represents a complex mixture of organic and inorganic substances. Particulate air pollution defined as "a mixture of solid, liquid or solid and liquid particles suspended in the air" (Dockery and Pope, 1997) is a big problem in major cities of the developed world, but it has also now become a serious and worsening situation in rapidly growing cities of the developing world, especially in Africa due to urbanization and industrialization. Ashaiman, a semi-urban area of Ghana is no exception. With the highest population growth rate in Ghana of about 4.6% (GSS, 2002), Ashaiman 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.

The evidence concerning links between ambient air concentrations of particulate matter, less than 10 and 2.5 μm in aerodynamic diameter (PM_{10} and $PM_{2.5}$ respectively) with a wide range of health effects has grown considerably in the recent decade. Both short term (24 h mean) exposure and long term (annual mean) exposures influence population health and hence the need for consented and more effective action to improve air quality (WHO, 2004).

The World Health Organization (WHO) 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). 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. For $PM_{2.5}$, the annual target is 35 $\mu g/m^3$, and the guideline is 10 $\mu g/m^3$.

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It is reasonable to ask how current ambient particulate matter concentrations in these developing countries compare with these values. Unfortunately, very little monitoring data exist upon which to base even a preliminary answer in these parts of the world.

The lack of ambient monitoring data for particulate matter in these areas severely hinders the ability to describe temporal and spatial patterns of concentrations, to characterize exposure-response relationships for key health outcomes, to estimate disease burdens, and to promote policy initiatives to address air quality. 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). In Ghana, collaboration between the US Environmental Protection Agency (US-EPA) and the United Nations Environmental Program (UNEP) started in 2005. This collaboration has led to the development of air monitoring networks in Accra, and is control by the Ghana.

Environmental Protection Agency. Most of the activities are designed to measure total suspended particulates and gases and thus only few aerosol particulate characteristics have been measured. The Environmental Protection Agency so far carried out the following activities in the country in the field of air pollution:

- Air Quality Management in Takoradi at the Thermal Power Station
- Bio-monitoring of Air Pollution using lichens
- Air pollution monitoring of Kpone and Tema Oil Refinery

In addition to these projects the Environmental Protection Agency (EPA) has a number of mobile stations, which they use to measure NOx, SOx and TSP but not on regular and sustained basis. So far nothing has been done on black carbon concentration measurement.

Virtually all air pollutions are emitted within the troposphere. It is impossible to make a list of all pollutants affecting air quality, but the two major classes are gaseous pollutants and particle pollutants. This project focused on carbonaceous particles which are mainly combustion aerosols of primary and secondary origin separated into two; organic carbon and black or elemental carbon. Particulate black carbon is one of the most important components in atmospheric aerosol. Even though it has long been one of the most elusive aerosol species, black carbon 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. Not only does it absorb sunlight, it reduces visibility, is associated with serious health effects, and causes global warming.

Particulate matter 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 Particulate Matter (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 mass of particulate matter and also to ascertain the level of atmospheric black carbon pollution within Ashaiman, a sprawling "urban slum" in the Greater Accra Region of Ghana and make contributions to air quality management in Ghana. This is to assist Health and Environmental authorities to take the necessary remedial measures.

Specifically, the objectives of the study are:

- To establish daily, weekly and monthly variation in inhalable particulate matter, and black carbon concentrations
- To determine the levels of black smoke pollution in order to highlight periods of elevated concentrations beyond the WHO acceptable limits
- To provide a database of suspended particulate matter (as Black Smoke) within Ashaiman for the study period since no atmospheric black carbon concentration data is currently available
- To monitor and make contributions to air quality management in Ghana

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 PM_{10} 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 PM_{10} fraction has a pore size of 2.0 μm and 47 mm in diameter. That of the $PM_{2.5}$ fraction is 0.2 μm 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 PM_{10}, $PM_{2.5}$ 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 (μg/m^3).

The equation governing the gravimetric analysis is given below:

$$C_{PM} = \frac{m}{V} \quad (1)$$

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:

$$RZ = RZ_{\max}(U_{RZ0} - U_{RZ\max})(U_{RZ0} - U_{RZ\max}) \quad (2)$$

where

U_{RZ0} = Ooutput 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:

$$C_R = -(RM_1 / V)\ln(1-(RZ - RZ_0)/(kRZ_{\max}) \quad (3)$$

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
RZ_{max} = The black smoke number for a black filter
K = Calibration constant

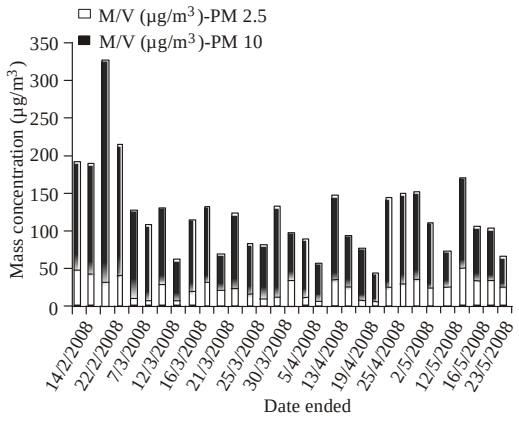

Fig. 1: Particulate mass concentrations

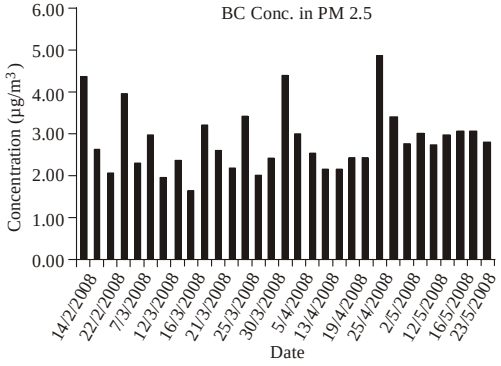

Fig. 2: $PM_{2.5}$ black carbon mass concentration

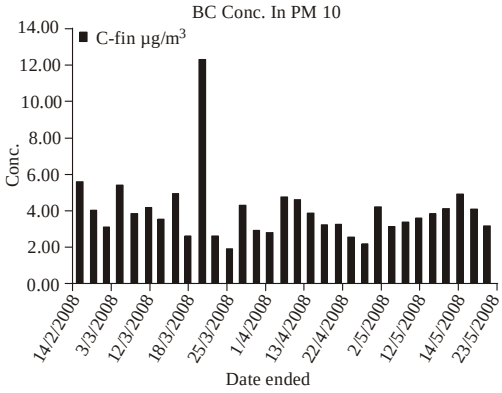

Fig. 3: PM_{10} black carbon mass concentration

Finally, C_R 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

Mass concentrations (µg/m³) and Black Carbon (BC) concentrations (µg/m³) in ambient air: For the period of study, the semi-urban background total mass concentration (µg/m³) of $PM_{2.5}$ and PM_{10} collected on the filters varied from day to day. Table 1 gives the mean mass concentrations of $PM_{2.5}$ and PM_{10}, black carbon concentrations and the percentage black carbon concentrations in $PM_{2.5}$ and PM_{10}. The maximum and the minimum values of these parameters provided inTable 1 gives an indication to how widely they varied from day to day.

Table 1: Mass concentrations (µg/m³), and Black Carbon (BC) concentrations (µg/m^{-3}) in ambient air in Ashaiman between February and May, 2008

Property	Maximum	Minimum	Mean
$PM_{2.5}$/ µg/m³	46.43	3.85	23.26
PM_{10}/ µg/m³	293.06	37.10	96.56
BC ($PM_{2.5}$)/ µg/m³	4.89	1.67	2.83
BC (PM_{10})/ µg/m³	12.44	1.99	3.98
%BC ($PM_{2.5}$)	63.14	6.12	18.40
%BC (PM_{10})	12.62	1.07	4.86

Table 2: Concentration ratios of PM_{10}, $PM_{2.5}$ and BS

Property	Maximum	Minimum	Mean
$PM_{2.5}/PM_{10}$	0.537	0.067	0.300
$BC/PM_{2.5}$	0.631	0.061	0.184
BC/PM_{10}	0.126	0.011	0.049
$PM_{10-2.5}$/µ/g³	261.810	20.252	73.304

PM_{10} mass concentration is much higher (about 5 times) compared to the fine ($PM_{2.5}$) fraction. 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}.

The percentage of Black Carbon (BC) concentration levels in $PM_{2.5}$ and PM_{10} were calculated to ascertain the percentage of BC in the fine ($PM_{2.5}$) and coarse (PM_{10}). This also varied from day to day and as anticipated, $PM_{2.5}$ is dominated by black carbon (carbonaceous combustion) component. For $PM_{2.5}$, it averaged 18.4% (6.1-63.1%) which was much higher than that of PM_{10}. Percentage black carbon concentration in PM_{10} averaged 4.9% (1.1 - 12.6%). This indicates that black carbon is dominant in the fine particulate matter.

The daily variations of $PM_{2.5}$ and PM_{10} and their respective BC concentration variations are presented in Fig. 1-3.

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 µg/m³ and extend down to the 20 µg/m³ guideline and for $PM_{2.5}$, the first annual target is 35 µg/m³, and the guideline is 10 µg/m³.

Clearly, the average PM_{10} value for this study exceeded WHO guideline and that of $PM_{2.5}$ is very close to WHO limit value.

Aboh and Ofosu (2005/2006), reported a daily mean $PM_{2.5}$ and PM_{10} concentrations of 4.3 and 59.7 µg/m³ at a site located in Kwabenya near Accra, Ghana (within the same region) during 2005/06 harmattan. These values are

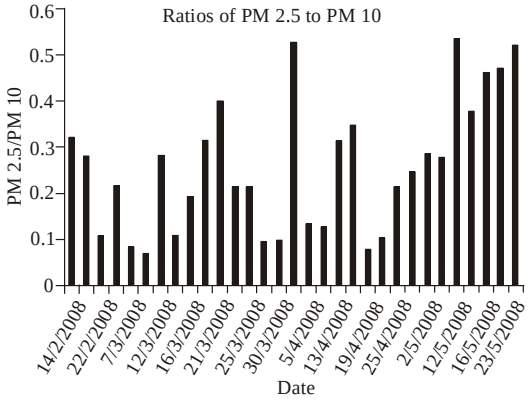

Fig. 4: Ratios of $PM_{2.5}$ to PM_{10}

much lower than the results from Ashaiman, the difference in mean 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 Fig. 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 PM_{10} fraction.

Particles which are suspended by vehicular movement on paved and unpaved roads are a major contributor to fugitive dust emissions (Etyemezian *et al*., 2003). Construction of roads and other infrastructure, which are common in this area, also played a major role in the coarse fraction.

According to World Health Organization (WHO, 2005) report, the evidence of the association between airborne particulate matter and public health outcomes is consistent in showing adverse health effects at exposures experienced by urban populations in cities throughout the world, in both developed and developing countries. The risk for various outcomes has been shown to increase with exposure and there is little evidence for a threshold below which no adverse health effects would be anticipated.

Concentration ratios of PM_{10}, $PM_{2.5}$ and Black Carbon (BC): From Table 2, the calculated $PM_{2.5}$ to PM_{10} ratio, even though, the mean value of 0.30 is on a lower side and the $PM_{2.5\text{-}10}$ concentrations ($PM_{2.5\text{-}10}$, calculated as difference between PM_{10} and $PM_{2.5}$ concentrations) recorded a high mean value of 73.30 μg/m^3 indicating that most of the aerosols measured are in the coarse mode. The maximum and minimum values of $PM_{2.5}$ to PM_{10} ratio (μg/m3 2) gives an indication to how widely these ratios varied from day to day. Figure 4 suggest that the ratio is high in some cases. Maximum $PM_{2.5}/PM_{10}$ ratios are often associated with local pollution episodes that are associated to combustion sources (Marcazzan *et al.*, 2002) and Ashaiman is especially prone to experience local pollution episodes because, Ashaiman is characterized by a lot of open burning, household wood and charcoal burning and local traffic. 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 PM_{10}, it has been found to be about 0.4% (μg/m^3 2). It followed from these values that black carbon constitutes a greater fraction if not dominated in the fine particulate matter. Fine fraction contains most of the respirable particulate matter and mostly generated by combustion activities.

CONCLUSION

From the results obtained it can be seen that the semi-urban background aerosol of Ashaiman, is not only largely made up of combustion generated carbonaceous particles but particles from natural activities that resulted in high PM_{10} value. The mean values of 23.26 μg/m^3 and 96.56 μg/m^3 obtained for $PM_{2.5}$ and PM_{10} respectively are on a higher side. PM_{10} mean value exceeded the WHO guideline and the Ghana Environmental Protection Agency (Ghana EPA) guideline value (70.0 μg/m^3 for 24 hour average and 50 μg/m^3 yearly average). More work needs to be done in fine particulate measurement, since the mean value obtained is very close to WHO limit value and Ghana EPA is yet to set a guideline value for fine particulates ($PM_{2.5}$). In addition, there is the need for modelling of these aerosol samples to identify the sources and the quantities from those sources.

The low mean value of 0.3 for the $PM_{2.5}$ to PM_{10} ratio and the mean of 73.30 μg/m^3 for the coarse fraction ($PM_{10\text{-}2.5}$) suggest that most of aerosol measured are in the coarse mode. Also, some of the values from the $PM_{2.5}$ to PM_{10} ratios resulted in high values suggesting instances of high local pollution such as open burning, domestic wood and charcoal burning and local traffic. The BC fraction of coarse is about 0.4% and that of the fine is 18%. These values are very high compared to results from some literature and WHO guideline, especially that of the fine hence the need for future measurements. Black carbon is dominated in the fine particulate.

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