PARTICULATE MATTER AND BLACK CARBON CONCENTRATION LEVELS IN ASHAIMAN, A SEMI-URBAN AREA

BY

SAM-QUARCOO DOTSE

THIS THESIS IS SUBMITTED TO THE UNIVERSITY OF GHANA, LEGON

IN PARTIAL FULFILLMENT OF THE REQUIREMENT FOR THE AWARD OF M. PHIL. PHYSICS DEGREE

AUGUST, 2008.
CONTENT

DECLARATION

DEDICATION

ABSTRACT

ACKNOWLEDGEMENT

CHAPTER ONE

1.0 INTRODUCTION

CHAPTER TWO

2.0 PARTICULATE MATTER

2.1 SIZES OF ATMOSPHERIC PARTICLES

2.2 URBAN AEROSOL PARTICLES FROM DIFFERENT SOURCES

2.3 ANTHROPOGENIC SOURCES

2.3.1 Stationary Combustion Sources

2.3.2 Non Combustion Sources

2.3.3 Road Transport

2.3.4 Other Anthropogenic Sources

2.4 NATURAL SOURCES

2.4.1 Soil Re-suspension

2.4.2 Long Range Dust Transport

2.4.3 Sea Spray

2.4.4 Volcano Emissions
2.5 EMISSION, TRANSPORT, TRANSFORMATION AND SAMPLING OF AIRBORNE POLLUTANTS

2.6 ELEMENTAL OR BLACK CARBON

2.7 HEALTH EFFECTS

2.8 PARTICULATE MATTER SAMPLING

2.8.1 Inertial Sampling Devices

2.8.2 PM$_{2.5}$ and PM$_{10}$ Inertial Particle Size Separator

2.9 SMOKE STAIN REFLECTOMETER (SSR)

CHAPTER THREE

3.0 MATERIAL AND METHODS

3.1 STUDY AREA AND MEASUREMENT PERIODS

3.2 SAMPLING EQUIPMENT AND METHODS

3.3 GRAVIMETRIC ANALYSIS

3.4 SMOKE STAIN REFLECTOMETER

3.4.1 Preparation of the SSR Instrument

3.4.2 Calibration

3.4.3 Measurement of Reflectance (the output voltage)

3.5 ANALYSIS OF BLACK SMOKE

3.6 QUALITY CONSIDERATIONS

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 MASS CONCENTRATIONS ($\mu$gm$^{-3}$) AND BLACK CARBON (BC) CONCENTRATIONS ($\mu$gm$^{-3}$) IN AMBIENT AIR
4.2 CONCENTRATION RATIOS OF PM$_{10}$, PM$_{2.5}$ AND BLACK CARBON (BC)

4.3 LIMITATIONS AND SOURCES OF ERROR IN INERTIAL COLLECTION.

4.4 METEOROLOGY

CHAPTER FIVE

5.0 CONCLUSIONS

REFERENCES

APPENDIX
DECLARATION

I hereby declare that except for references to other peoples work, which have been duly cited, this work is the result of my own research and that it has neither in part nor whole been presented for any degree elsewhere.

(SAM-QUARCOO DOTSE)

STUDENT

(EVANG. PROF. E.K. OSAE)

SUPERVISORS

(DR. V. C. K. KAKANE)

(MR. I. J. K ABOH)
DEDICATION

THIS THESIS IS DEDICATED TO MY PARENTS MR. SAMUEL KOFIG DOTSE AND MADAM SABUTEY DORA AND TO MY SIBLINGS: SAMSON, ESENM, AFI, PEARL AND EL-DORA FOR THEIR SUPPORT DURING THE COURSE OF MY STUDY.
ACKNOWLEDGEMENT

I am very grateful to the Almighty God for his grace and wisdom throughout the course of my study. With gratitude I reckon the contributions of Evang. Professor E.K. Osae, Dr. V.C.K. Kakane of University of Ghana, Legon and Mr. I.J.K. Aboh of Ghana Atomic Energy Commission (G.A.E.C) for their supervision and direction. Their criticisms, suggestions as well as advice have been an invaluable help to me. I also wish to express my gratitude to Mr. F.G. Ofosu of the X.R.F Laboratory, G.A.E.C for his supervision in the form of careful scrutiny and useful suggestions which contributed greatly to the success of this work.

My profound gratitude goes to the Headmaster, Staff and students of Ashaiman Senior High School for allowing me space to mount my samplers and also providing security and electricity for the equipments free of charge.

My sincere thanks also go to the G.A.E.C for the use of its facilities.

Special thanks go to both teaching and non-teaching staff of the Physics Department, University of Ghana - Legon.

Finally, I am greatly indebted to my parents who have laboured for me to be educated to this level and for their immense contribution and financial support.

SAM-QUARCOO DOTSE

LEGON

AUGUST, 2008
ABSTRACT

Using IVL PM$_{2.5}$ and PM$_{10}$ particle samplers, airborne particulate matter was sampled from Ashaiman, 30 km from Accra-capital of Ghana.

The airborne particles were collected 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 μgm$^{-3}$ (3.85 - 46.43 μgm$^{-3}$) and that of PM$_{10}$ was 96.56 μgm$^{-3}$ (37.10 - 293.06 μgm$^{-3}$).

The results were compared with some literature values and World Health Organisation 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.
CHAPTER ONE

1.0 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 et al., 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% (TMA, 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\textsubscript{10} and PM\textsubscript{2.5} respectively) with a wide range of health effects has grown considerably in the recent decade. Both short term (24-hour 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\textsubscript{10} and PM\textsubscript{2.5} as well as interim target concentrations for use by developing countries in measuring progress towards the guideline concentrations (WHO 2006). PM\textsubscript{10} interim targets for annual average concentrations start at 70 μg m\textsuperscript{-3} and extend down to the 20 μg m\textsuperscript{-3} guideline. For PM\textsubscript{2.5}, the annual target is 35 μg m\textsuperscript{-3}, and the guideline is 10 μg m\textsuperscript{-3}. 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; 1995, Kent; 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 (BC) Carbon 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.
CHAPTER TWO

2.0 PARTICULATE MATTER

Particulate matter, or PM, is the term for particles found in the air, including dust, dirt, soot, smoke, and liquid droplets. Particles can be suspended in the air for long periods of time. Some particles are large or dark enough to be seen as soot or smoke. Others are so small that individually they can only be detected with an electron microscope.

Particulate matter come from a variety of sources such as cars, trucks, buses, factories, construction sites, tilled fields, unpaved roads, stone crushing, and burning of wood. Other particles may be formed in the air from the chemical change of gases and when gases from burning fuels (gaseous precursors such as sulphur dioxide, nitrogen oxides, or organic compounds) react with sunlight and water vapour. These particles can be classified in several ways based on their formation mechanism, size, origin, chemical composition, atmospheric behaviour and method of measurement.

Based on the mechanism of their formation, particles can be classified into primary and secondary particles. Primary particles are emitted directly as particles, whereas secondary particles are formed from precursor gases in the atmosphere via gas-to-particles conversion. Both types of particles are subject to growth and transformations since there can be formation of secondary material on the surface of existing particles.
The particle size is the single most important determinant of the properties of particles and it has implications on formation, physical and chemical properties, transformation, transport, and removal of particles from the atmosphere. The size ranges from a few nanometers (nm) to tens of micrometers (μm). Particles are sampled and described on the basis of the particle size normally given as the aerodynamic diameter, which refers to the diameter of a unit density sphere of the same settling velocity as the particle in question. The notation PMx refers to particulate matter comprising particles less than X μm in diameter (most often, X is 10, 2.5 or 1 μm). Particles greater than 2.5 μm in diameter are generally referred to as coarse particles, and particles less than 2.5 μm and 100 nm in diameter as fine particles and ultrafine particles, respectively. The term total suspended particles (TSP) refers to the mass concentration of particles less than 40 to 50 μm in diameter (Seinfeld and Pandis 1998).

Even though, in Particulate air pollution studies, it is convenient to classify particles by their aerodynamic properties, the broadest classification differentiates between the origins (sources); natural and anthropogenic (man-made) sources. The concentration of particles in the air varies across space and time, and is related to the source of the particles and the transformations that occur in the atmosphere. Natural sources include forest fires, sea spray, volcano eruptions and wind-blown dust. Examples of anthropogenic sources are emissions from industries, burning of fossil fuel, combustion processes and traffic emissions. It is not always easy to distinguish between natural and
anthropogenic sources. For example, biomass burning and soil dust emissions can be of either type.

2.1 SIZES OF ATMOSPHERIC PARTICLES

Atmospheric aerosols consist of particles ranging in size from a few tens of angstroms (Å) to several hundred micrometers (µm), having typically a modal size distribution (Seinfeld and Pandis 1998). Meaning that the total mass of particulate matter tends to concentrate around one or more distinguishable points on the particle size scale. The number of observable modes in particle size distribution varies depending on age of the aerosol and the vicinity of active sources of particles of different sizes. The reason for this variation is twofold. The modal character of the particle mass size distribution results continuous processes leading to formation of particle and on the other hand, processes leading to removal of particles from the atmosphere.

The phenomena that influence particle sizes are shown in an idealized schematic in Figure 2.1, which depicts the tri-modal distribution of atmospheric particles together with the major formation mechanism (Whitby, 1978).
Figure 3.1. Schematic representation of the tri-modal distribution of atmospheric particles together with the major formation mechanisms. (Adapted from Whitby (1978).)
The three groups shown are the nucleation mode (also known as 'nuclei mode' or the 'Aitken nuclei mode'), accumulation mode and coarse mode, with size ranges of about <0.1 µm, 0.1-2 µm and >2 µm, respectively (Colbeck, 1995).

Particles in the nucleation mode are usually called "ultrafine particles" and are primarily produced through gas-to-particle conversion or combustion processes. The two smaller modes are often combined as the fine particle mode. The upper cut-off size of coarse particle samplers is usually 10 µm since particles larger than 10 µm are believed to have little health significance (Harrison et al., 1999; Hinds, 1999).

The two most common measures for collection of particulate matter are PM$_{10}$ and PM$_{2.5}$. They are defined as the mass of particulate matter passing a selective inlet (e.g., an inlet cyclone) with a 50% cut-off diameter of 10 and 2.5 µm, respectively.

The actual shape and density of aerosol is not known and therefore, a shape-independent way to describe it is by using the concept of aerodynamic diameter. The equation 2.1 below (Hinds, 1999) can be used to calculate the aerodynamic diameter, $d_a$.

\[ d_a = \sqrt{\frac{18\eta V_{TS}}{\rho_o g}} \]  \hspace{1cm} \text{......... 2.1}

Where, $\eta$ is the viscosity of air, $V_{TS}$ is the gravitational settling velocity, $\rho_o$ is the density of water and $g$ is the acceleration of gravity.
The settling velocity is a measure of how fast a particle of a certain size will fall under gravity. In the equation above, \( \nu_{rs} \) is proportional to the square of the aerodynamic diameter. Consequently larger particles introduced into the atmosphere will not reside in the atmosphere for as long as smaller particles and will therefore not be able to travel long distances.

2.2 URBAN AEROSOL PARTICLES FROM DIFFERENT SOURCES

Particulate matter may be classified in several ways based on their size, mechanism of formation, origin, chemical composition, atmospheric behaviour, or method of measurement. The broadest classification of particulate matter however, differentiates between the natural and anthropogenic (man-made) sources. Significant portion of the total particulate matter emissions to the atmosphere are attributable to natural sources, such as suspended terrestrial dust, oceans and seas, volcanoes, forest fires and natural gaseous emissions. However, these emissions are dispersed rather evenly into the atmosphere and, therefore, result in a relatively low tropospheric background particulate matter concentration. Urban particulate matter from man-made sources is a complex mixture, since the majority of sources emit both primary particles and precursor gases for the formation of secondary particles. Emissions of particulate matter attributable to human activities include transportation, stationary combustion, space heating, biomass burning, and industrial and traffic-related fugitive emissions (street dust).
Air samples of particulate matter from urban areas from around the world typically show the same major components, although in considerably different proportions according to the sampling location (Harrison & Yin, 2000). These major components are typically:

1. **sulphate** - derived predominantly from sulphur dioxide oxidation in the atmosphere; because SO₂ is oxidised only slowly, spatial gradients of sulphate on a scale of tens of kilometres are expected to be small, over hundreds of kilometres they can be significant, and over entire continents, very large;

2. **nitrate** - formed mainly from oxidation of nitrogen oxides (NO and NO₂) to nitrate; NO₂ oxidises much more rapidly than SO₂

3. **ammonium** - atmospheric ammonia forms ammonium salts in neutralisation reactions with sulphuric and nitric acids

4. **chloride** - main sources are sea spray and de-icing salt during winter; also from ammonia neutralisation of HCl gas from incineration and power stations

5. **elemental carbon (EC) and organic carbon (OC)** - combustion processes (in urban areas mainly traffic) emit primary carbonaceous particles and semi-volatile precursors

6. **crustal materials** - soil dusts and wind-blown crustal material; are quite diverse in composition reflecting local geology and surface conditions; their concentration is dependent on climate as the processes which suspend them into the atmosphere tend to be favoured by dry surfaces and high winds;
these particles reside mainly in the coarse particle fraction (Harrison et al. 1997)

7. **biological materials** - bacteria, spores, pollens, debris and plant fragments; generally coarse in size, considered as part of the organic carbon component in most studies rather than as a separate biological component.

The distinction between anthropogenic and natural particle sources and the emitted particulate matter is sometimes difficult to make, for example, fugitive dust emissions and biomass burning. In addition, there are large differences in the relative importance of different sources from one geographical area to another. The following sections give a classification of atmospheric particles from different sources.

2.3 **ANTHROPOGENIC SOURCES**

2.3.1 **Stationary Combustion Sources**

The most significant stationary combustion sources include energy production facilities such as municipal power plants, waste incineration, and domestic or residential combustion. Several industrial processes, such as iron and steel production, also involve combustion of fossil fuels or biomass for generating power and heat needed for the process. Most of these sources are considered *point sources*, although smaller and more widespread sources such as residential combustion could also be considered as a *point source*. Physical and
chemical characteristics of the particles emitted from these source categories depend on the combustion process itself, and the type of fuel burnt (solid, liquid, or gas).

Industrial emissions can be a significant source of particulate emissions in urban areas. The contribution that this source makes to ambient particulate material will vary depending on the location of the industry and the abatement technology adopted. Although many studies have been conducted to characterize emissions from large industrial sources, for example steel works, information on small urban emitters, for example metallurgical processes and small factories, is more limited. Particles emitted from industrial sources have been found to be in the size range of 0.5 μm to some 100 μm, depending on the nature of the source. Composition also depends on the nature of the source.

Two main types of pollutants; combustion gases and fly ash are emitted from incinerators. Fly ash is composed of soot, trace metals, mineral dust, and partially burnt material with a size distribution between 5 μm and some 150 μm. Both the size of the fly ash and the amount emitted are specific to individual incinerators and on the nature of the particulate scrubbers in use. Also, for a specific incinerator the particle emission varies during operation. Ash recovered in the scrubbers system has to be correctly disposed of, in a controlled landfill, to avoid the emission of fugitive dust (Pavoni et al., 1975).

Accidental fires originating in uncontrolled waste landfill can produce high levels of particulate emission.
2.3.2 Non-Combustion Sources

Other non-combustion sources like construction, quarrying and mining, cement plant and ceramic industry also contribute to the total suspended particulate mass. It is however difficult to assess or quantify the amount and composition of particles emitted from these sources because of their physical and chemical composition.

Depending upon the mechanical activity, rock type and wind speed, the majority of the mass of fugitive aerosol (dust) emitted from quarrying and mining activities, construction and demolition work is expected to be present in general in sizes above 3 μm particle diameter. A small amount of these particles can also be contained in the size range between 1 and 3 μm (US-EPA 1995).

The quantity of particles emitted from construction and demolition work will depend on the type of construction in progress. These particles are mainly present in size fractions greater than 10 μm. However, some fraction of the total amount is likely to be present as smaller particles. Some of this dust will be re-suspended either by traffic or wind.

2.3.3 Road Transport

Particulate emissions from road transport arise as direct emissions from vehicle exhausts, tyre and brake wear and re-suspension of road dust. In urban areas, emissions from road transport are thought to be the major source of PM$_{10}$. In
general, diesel engine vehicles emit a greater mass of fine particulate matter, per vehicle, than petrol engines.

Diesel emissions are mainly composed of soot particles, volatile hydrocarbons and some sulphate from the fuel sulphur. When hydrocarbons and sulphates are released by the car exhaust they condense on airborne particles, mainly on the freshly emitted carbon. The size distribution of these particles tends to be bimodal, with particles of 0.01 to 0.05 μm in the nucleation mode in the case of freshly emitted soot particles and, of some 0.05 to 2.5μm in the accumulation mode in the case of older coagulated soot particles.

The movement of vehicles on the street also results in re-suspension of road dust. Emissions also occur as a result of tyre wear and brake lining wear. Although there is a lack of data, it is expected that most of these particles will be in the size range of 3 to some 30μm. The chemical composition of these particles may also be very different from those derived from combustion.

The road dust deposit available for re-suspension comes from mechanical wear of, and dirt on, vehicles (including tyre and brake lining wear), debris from loads on vehicles, influx of soil material.

2.3.4 Other Anthropogenic Sources

Both direct emission from fires and ash re-suspension from burnt soils could be an important source of airborne PM$_{10}$. This material, which is composed of
organic matter, black carbon and inorganic material, is to a large extent present in the size range below 10 μm and so can be re-suspended by wind (Crutzen & Andreae, 1990).

Although the contribution to ambient aerosol from fire smoke will generally be episodic, in areas where there is a constant forest burning, the particulate emission from this source could be significant. In developing countries like Ghana, agricultural fire emissions are mainly due to stubble burning. It can be expected to be a significant source of particles.

Emissions of wind-blown soil dust can occur from bare fields, especially in dry periods. These particles are likely to be relatively large and will not, in general, contribute significantly to overall PM$_{10}$ levels.

2.4 NATURAL SOURCES

2.4.1 Soil Re-suspension

The term re-suspension is commonly used to include both suspension of newly generated particles and re-entrainment of previously deposited particles into the atmosphere (Nicholson 1988). Meteorological mechanisms such as wind, temperature changes and water produce soil dust by either rock or mineral weathering. This dust can be carried by wind and has a particle size distribution depending upon its original geological source (Warneck 1988) and can be in the size range between 5 to 50μm. However, fine sand has a log normal distribution.
around a particle size of about 10μm. The chemical composition of soil particles is similar to their geological origin as dolomite, gypsum quartz and clay minerals. Usually, an analysis showing enrichment in silicon, calcium, iron and aluminium in the aerosol indicates its geological origin.

The action of the wind on dry loose soil surfaces leads to particles blowing into the air. Factors favouring the suspension of soil dust particles into the atmosphere are an exposed dry surface of fine soil and a high wind speed. In towns and cities, the areas of exposed soil, particularly in town centres, are rather small. However, there are considerable quantities of dusts on road and pavement surfaces which arise from ingress of soil on vehicle tyres and from the atmosphere, the erosion of the road surface itself and degradation of parts of the vehicle, especially the tyres. Because these particles lie on a surface which readily dries and is subject to atmospheric turbulence induced by passing vehicles, this provides a ready source of particles for re-suspension into the atmosphere. The amounts of dust re-suspended in this process are extremely difficult to predict or measure, as they depend critically upon factors such as the dust loading of the surface, the preceding dry period and the speed of moving traffic. However, the size distribution and chemical composition of particles in the atmosphere give a clear indication that this source can contribute significantly to the airborne particle loading of our cities.
2.4.2 Long Range Dust Transport

A source of airborne particulate matter that cannot be neglected is the injection of windblown natural dust into the atmosphere in sand and dust storms common during windy conditions in the world's deserts. In the northwestern Mediterranean region, the input of Saharan material, known locally as red rains, has been estimated as 3.9 million tonnes each year (Loye-Pilot et al. 1986). In some parts of the Mediterranean basin, it is thought that this makes a substantial contribution to local airborne particulate matter.

These processes do extend to other regions of the globe, although their magnitude is obviously reduced where soils are moist and have vegetation cover. Much enhanced deposition is occasionally seen when the atmosphere carries dust from the Sahara desert regions. Such particles are generally rather coarse which usually have only a limited atmospheric lifetime and range.

The harmattan, a dry desert wind from the Sahara, blows from the northeast from December to March, lowering the humidity and creating hot days and cool nights in the north. In the southern part of the country, the effects of the harmattan are felt in January and February. It has been shown by Baumbach et al. (1995) that in Lagos-Nigeria the particle concentration more than doubled during the dry season when the north harmattan wind from the Sahara are prevalent.

The status of the road network in Ghana especially in the rural areas whereby a lot of roads are unpaved plays a significant role in the entrainment of dust;
particles which are suspended by vehicular movement on paved and unpaved roads are a major contributor to fugitive dust emissions (Etyemezian et al., 2003).

2.4.3 Sea Spray

Breaking waves on the sea cause the ejection of many tiny droplets of seawater into the atmosphere. These droplets dry by evaporation leaving sea salt particles suspended in the air. Particles are also directly emitted by the bursting of air bubbles on sea surface. Such particles are generally in the size range between 1 to 20μm (Blanchard & Woodcock 1980). Whilst these particles are, in the main, rather coarse in size, a minor part of their mass is in particles small enough to have an appreciable atmospheric lifetime, which has been estimated as three days (Junge 1972). Clearly, coastal areas will be the most affected, but sea salt is also measurable at inland locations.

Ghana has 537-kilometer (334-mi) coastline which is mostly a low, sandy shore backed by plains and scrub and intersected by several rivers and streams. Common salt is produced in commercial quantities along the coast of Ghana near Accra (at Ada). Half of the country of Ghana lies less than 152 meters (500 ft.) above sea level, and the highest point is 883 meters (2,900 ft.). The general wind direction is North-East in the southern part of the country and depth of penetration of the coastal wind is high, sometimes covering more than two/thirds of the country.
Airborne sea salt shows a similar chemical composition to sea salt, with anions (chloride and sulphate), cations (sodium and magnesium) and organic phosphorus. Trace metals (cadmium, lead, vanadium, and zinc) have been found in marine aerosol. This aerosol metal enrichment arises from bubbles of water scavenging before bursting.

2.4.4 Volcanic Emissions

Fine fly ash emitted from volcanoes could represent an important local source of \( \text{PM}_{10} \) particles. Emissions of sulphur dioxide (SO₂) from volcanoes can also contribute to the formation of secondary particles. However volcanic activity does not normally occur in our part of the world and as such has no significant impart on particulate matter pollution.

2.5 EMISSION, TRANSPORT, TRANSFORMATION AND SAMPLING OF AIRBORNE POLLUTANTS

Particles of different sizes often have a different origin and also a different composition (Seinfeld and Pandis, 1998). Air pollution transport is governed by the speed and direction of the wind. The rate of dispersion is influenced by the thermal structure of the atmosphere as well as by mechanical agitation of the air as it moves over the different surface features of the earth. Transformation of the emitted air pollutants is impacted by exposure to solar radiation and moisture as
well as other constituents in the atmosphere. The removal of pollutants depends not only on the characteristics of pollutants but also on weather phenomena such as rain, snow and fog.

Coarse particles are generally not transported far but exceptions do occur. A volcano eruption is an example of such exceptions. During an eruption, the volcano emits an enormous number of particles, both fine and coarse, vertically at very high velocity. The plume is transported high up into the atmosphere, even up to the stratosphere, and therefore can be transported over very long distances. The volcanic cloud from the Mount Pinatubo eruption in 1991 encircled the earth within 22 days (Timmreck et al., 1999). Also, sometimes special meteorological conditions can favour long-range transport of coarse particles. For example, this occurred in October 2001 when Saharan dust was transported all the way north to southern Scandinavia and deposited in the area around Göteborg (Ullgren, 2001). A summary of emission, transport, transformation and sampling of airborne pollutants is presented in figure 2.2.

Fine particles as an entity are more intricate to describe in general terms since they often undergo transformations in the form of both chemical reactions and particle growth (Finlayson-Pitts & Pitts, 2000; Seinfeld & Pandis, 1998). In the trimodal distribution of atmospheric particles, the primary produced nucleation mode particles grow quickly into the accumulation mode range, where their growth rate slows down. An effect of this is that nucleation mode particles do not travel very far before they are transformed into accumulation mode particles. This means that nucleation mode particles, measured by counting or collection, are
well as other constituents in the atmosphere. The removal of pollutants depends not only on the characteristics of pollutants but also on weather phenomena such as rain, snow and fog.

Coarse particles are generally not transported far but exceptions do occur. A volcano eruption is an example of such exceptions. During an eruption, the volcano emits an enormous number of particles, both fine and coarse, vertically at very high velocity. The plume is transported high up into the atmosphere, even up to the stratosphere, and therefore can be transported over very long distances. The volcanic cloud from the Mount Pinatubo eruption in 1991 encircled the earth within 22 days (Timmreck et al., 1999). Also, sometimes special meteorological conditions can favour long-range transport of coarse particles. For example, this occurred in October 2001 when Saharan dust was transported all the way north to southern Scandinavia and deposited in the area around Göteborg (Ullgren, 2001). A summary of emission, transport, transformation and sampling of airborne pollutants is presented in figure 2.2.

Fine particles as an entity are more intricate to describe in general terms since they often undergo transformations in the form of both chemical reactions and particle growth (Finlayson-Pitts & Pitts, 2000; Seinfeld & Pandis, 1998). In the trimodal distribution of atmospheric particles, the primary produced nucleation mode particles grow quickly into the accumulation mode range, where their growth rate slows down. An effect of this is that nucleation mode particles do not travel very far before they are transformed into accumulation mode particles. This means that nucleation mode particles, measured by counting or collection, are
generally locally produced in contrast to the larger size fraction of the fine particles.

Figure 2.2 Schematic Diagram outlining Emission, Transport, Transformation and Sampling of airborne pollutants
generally locally produced in contrast to the larger size fraction of the fine particles.

Figure 2.2 Schematic Diagram outlining Emission, Transport, Transformation and Sampling of airborne pollutants
2.6 ELEMENTAL OR BLACK CARBON

The carbonaceous fractions of ambient particulate matter consists of \textit{elemental} (EC) or \textit{black} (BC) carbon and \textit{organic} carbon (OC) as well as a small percentage (less than 5%) of inorganic carbon mainly present as carbonate. Organic Carbon which constitutes up to 70\% of the total atmospheric dry fine particle mass has both primary and secondary origin. Primary OC is mainly formed during combustion processes such as un-leaded gasoline combustion in urban area or biomass and field agricultural burning (Duan et al., 2004). It is also directly emitted as plant spores, pollens and soil organic matter. Secondary OC can originate from different processes such as gas to particle conversion of low vapour pressure volatile organic compounds, condensation and physical and chemical adsorption.

Elemental carbon is essentially a primary pollutant (Seinfeld & Pandis, 1998) emitted during incomplete combustion of fossil and biomass carbonaceous fuels. In urban areas, diesel emissions are one of the major sources for elemental carbon, which is often used as a marker for urban pollution (Delumyee et al., 1980; Salma et al., 2004); furthermore, its temporal pattern could be related to traffic intensity (Ruellan & Cachier, 2001).

It is more often called Black Carbon (BC) because of its colour. It has a graphitic-like structure with the presence of some functional groups containing elements such as oxygen, sulphur, hydrogen and nitrogen, which are able to enhance catalytic processes. When carbon to oxygen ratio during the
Combustion process is less than 1, then it is referred to as soot. Indeed soot, that represents the dark component of the carbonaceous aerosol, is a very complex mixture of both elemental carbon and highly polymerized organic substances.

The large concern on elemental carbon (EC) concentrations in particulate matter samples is due to the adverse health effects (Summerhays, 1991; Oberdorster & YU, 1990) and soiling of surfaces. At a global scale, EC might also play a role in radiative forcing effects, as it is the dominant light-absorbing component of atmospheric aerosols.

Since Black Carbon is the dominant light-absorbing substance in the atmosphere, it is possible to estimate elemental carbon (EC) concentrations in the atmosphere as Black Smoke (BS) by measuring light absorption or reflectance as Particulate Matter (PM) collected on filter media. This analytical method employed in this work is termed Reflectometric Method of determining Black Carbon (BC) concentrations using Smoke Stain Reflectometer. The darkness of the particulate sample is consequently an indication of the amount of Elemental Carbon (EC) on the filter and is often referred to as "Black Smoke (BS)".
2.7 HEALTH EFFECTS OF AEROSOLS

Many scientific studies have linked breathing of particulate matter to a series of significant health problems, including: aggravated asthma, increases in respiratory symptoms like coughing and difficult or painful breathing, chronic bronchitis, decreased lung function and premature death in the elderly.

Which particles are most hazardous to human health is not yet known but the size of the particle is a main determinant of where in the respiratory tract the particle will come to rest when inhaled. Larger particles are generally filtered in the nose and throat and do not cause problems, but particulate matter smaller than about 10 µm (PM$_{10}$), can settle in the bronchi and lungs and cause health problems.

The 10 µm size does not represent a strict boundary between respirable and non-respirable particles, but has been agreed upon for monitoring of airborne particulate matter by most regulatory agencies. Similarly, particles smaller than 2.5 µm (PM$_{2.5}$) tends to penetrate into the gas-exchange regions of the lung, and very small particles (< 100 nm) may pass through the lungs to affect other organs.

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. In one of WHO reports (WHO, 2004) it is stated that the public health significance of long-term health effects of exposure to particulate matter outweighs that of short-term effects. Short-term exposure effects have been documented in numerous time series studies, and guidelines for both the short (24 hours) and the long term (annual average) are recommended. The recommendation is that both PM$_{2.5}$ and PM$_{10}$ be assessed and controlled since fine and coarse particles have different sources and may have different effects. Regarding ultra-fine particles, information is insufficient to permit a quantitative evaluation of the risks of health effects of exposures (WHO, 2006). The recently adopted guidelines for annual means of particulate matter are 10 µg m$^{-3}$ and 20 µg m$^{-3}$ for PM$_{2.5}$ and PM$_{10}$, respectively, while for 24-hour means, they are 25 µg m$^{-3}$ and 50 µg m$^{-3}$ (WHO, 2006).

Concerning the question about which types (i.e. composition and size) of particles cause adverse health effects, and the types of effects caused, much is still unknown. Two recent review articles (Pope & Dockery, 2006; Schlesinger et al., 2006) discuss the current knowledge about particulate matter and particle size, and health effects. Both review articles conclude that there tends to be a stronger relation between fine particles, PM$_{2.5}$, and most health effects than between PM$_{10}$ and effects on health. Ultra-fine particles contribute little to the particulate matter mass concentration; however, they do influence the surface area by their large number and are of interest in toxicological studies (Schlesinger et al., 2006). Furthermore, since primary ultra-fine particles are a source of fine particles and since poorly soluble ultra-fine particles may be more likely than larger particles
to translocate from the lung to the blood and other parts of the body they are of importance in future studies.

People most at risk from exposure to Fine Particles includes; the elderly, individual with pre-existing heart or lung disease, asthmatics and asthmatic children. Studies estimate that tens of thousands of elderly people die prematurely each year from exposure to ambient levels of fine particles (ARB 2002a, & CDHS 2000). Studies also indicate that exposure to fine particles is associated with thousands of hospital admissions each year (CARB 2003a).

Many of these hospital admissions are elderly people suffering from lung or heart disease. Breathing fine particles can also adversely affect individuals with heart disease, emphysema, and chronic bronchitis by causing additional medical treatment (McConnell 2002). Inhaling fine particulate matter has been attributed to increased hospital admissions, emergency room visits and premature death among sensitive populations.

The average adult breathes 13,000 liters of air per day; children breathe 50 percent more air per pound of body weight than adults (Peters et al. 1999, Avol et al 2001, Gauderman et al. 2002). Because children's respiratory systems are still developing, they are more susceptible to environmental threats than healthy adults. Exposure to fine particles is associated with increased frequency of childhood illnesses, which are of concern both in the short run, and for the future development of healthy lungs in the affected children. Fine particles are also associated with increased respiratory symptoms and reduced lung function in children, including symptoms such as aggravated coughing and difficulty or pain.
PM$_{10}$ or other fractions of TSP. In practice most TSP inlets in fact have a particles size cut-off limit, which may or may not be well defined.

In most instruments, the particulate material is collected on a filter for either on-line or off-line weighing. The choice of filter material type is not generally critical, unless the filters are to be used for subsequent chemical analysis in addition to weighing. However, for accurate determination of filters by manual off-line methods, conditioning of the filter before pre- and post- weighing is essential to ensure that moisture absorbed by the filter does not interfere with the determination of the mass of the material collected.

Several analytical techniques are available today. Measurement of the mass of particulate matter collected can be undertaken by direct weighing either off-line or on-line. Alternately, surrogate methods of mass determination, such as $\beta$-absorption can be used. The choice of instruments used is based on the objectives of the study. Important factors are time resolution needed, particle size range of interest, and need of subsequent chemical analysis, as well as the number of instruments needed, the total number of samples and of course availability of instruments.

In the black smoke or black carbon method, measurement is usually made by determination of the reflectance of the filter stain by a calibrated Smoke Stain Reflectometer. Sampling of particles, reflectance measurements, and calculation to mass concentrations is done according to the ISO 9835 standard “Ambient air – Determination of a black smoke index” (ISO 1993).
2.8.1 INERTIAL SAMPLING DEVICES

The simplest way of collecting airborne particles is to draw air through a filter by using a filter cup connected to a pump and thus collect all suspended particles. Most widely used for limiting a size interval are different types of impactors that use the inertia of the particles following a bending airflow for collection of the particles. The principle of operation for the two most common types, the impactor and the cyclone, is shown in Figure 2.3. Impactors use the concept of particle inertia to size select and/or collect particles of the studied size range. (Peter Molnár 2007)

![Diagram of impactor and cyclone](image)

*Figure 2.3 Schematic drawings showing the principle of operation of an impactor (a) and a cyclone (b). (Peter Molnár 2007)*
A cyclone uses the same basic principle as an impactor, viz. that of particles moving along a bending air flow. Again, since larger particles cannot follow the bending air flow they impact on the cyclone wall while smaller particles follow the flow upwards and are collected on the filter. The main difference between impactors and cyclones is that impactors are designed to collect particles larger than the cut-off diameter while cyclones sort out and discard particles larger than the cut-off diameter. Furthermore, impactors can be designed to have a sharper cut-off function than cyclones.

Inertial collectors are designed to give a size representative sample of particles in the atmosphere using the principle that particles in a gas stream are more dense than the fluid (air) in which they are suspended. A particle moving in an air stream with approximately the same velocity as the air stream has more momentum than the volume of air that it displaces because of its higher mass. The momentum, or inertia, possessed by a particle in a moving air stream will cause the particle to be deflected less than the air in the vicinity of the particle when the air stream undergoes a sudden change in direction. Such a deflection will occur when an obstacle is placed directly in the path of an aerosol stream. If the resulting deflection of the particle from the air trajectory around the obstacle is great enough, the particle will strike the obstacle. High incident velocities will increase the momentum of particles in the air stream, thereby enhancing their removal. High velocities can be attained by passing the air stream through an orifice (jet) prior to the stream striking the obstacle (Figure 2.3).
Under the proper conditions, most of the particles within a certain size range that can be made to strike the obstacle will become attached to and remain on the collection surface.

No sampling device operates as a sharp step function, passing 100% of all particles below a certain size and excluding 100% of the particles larger than that size.

The inertial collection process is subdivided into two main types, impaction and impingement. The distinction is made by the manner in which the sample material is retained in the sampling device. Impingement devices differ from impactors because the jet and striking surface are immersed in a collecting fluid such as water. The particles that are removed from the aerosol stream are wetted by and retained in the fluid. Impingers are most commonly used in collecting dusts, mists, and fumes in the evaluation of occupational health hazards.

Impaction devices collect and retain particles from an aerosol stream on a collecting surface. The collecting surface is removed from the instrument and the sample analysis is, in many cases, performed directly on the collecting surface. Particle adhesion is caused primarily by electrostatic attraction and by molecular surface phenomena known as Van der Waals forces. Some loss of large particles occurs with high aerosol velocities. It is believed that in the case of small particles (several micrometers or less), nearly all of those striking the collecting surface are retained on the surface. The collection surface in many impaction devices is coated with a thin film of oil or light grease to aid in particle retention. In some
Under the proper conditions, most of the particles within a certain size range that can be made to strike the obstacle will become attached to and remain on the collection surface.

No sampling device operates as a sharp step function, passing 100% of all particles below a certain size and excluding 100% of the particles larger than that size.

The inertial collection process is subdivided into two main types, impaction and impingement. The distinction is made by the manner in which the sample material is retained in the sampling device. Impingement devices differ from impactors because the jet and striking surface are immersed in a collecting fluid such as water. The particles that are removed from the aerosol stream are wetted by and retained in the fluid. Impingers are most commonly used in collecting dusts, mists, and fumes in the evaluation of occupational health hazards.

Impaction devices collect and retain particles from an aerosol stream on a collecting surface. The collecting surface is removed from the instrument and the sample analysis is, in many cases, performed directly on the collecting surface. Particle adhesion is caused primarily by electrostatic attraction and by molecular surface phenomena known as Van der Waals forces. Some loss of large particles occurs with high aerosol velocities. It is believed that in the case of small particles (several micrometers or less), nearly all of those striking the collecting surface are retained on the surface. The collection surface in many impaction devices is coated with a thin film of oil or light grease to aid in particle retention. In some
devices, retention is aided by passing the incoming particles through a zone of moisture. Saturated air, moist particles adhere more readily to a collection surface.

Coating of the impactor plates and water saturation of the particles affect the calibration of an impactor and must be accounted for if the impactor is to be used for determining particle size distributions.

2.8.2 PM$_{10}$ or PM$_{2.5}$ Inertial Particle Size Separator

The IVL PM$_{2.5}$ and PM$_{10}$ samplers used in this project are based on inertial sampling method described in section 2.8.1. PM$_{10}$ or PM$_{2.5}$ Inertial Particle Size Separator provides for the measurement of the mass concentration of particulate matter with an aerodynamic diameter less than or equal to a nominal 10 or 2.5 µm in ambient air over a 24-hour sampling period. The sampler pulls ambient air at a volumetric flow rate into a specially shaped inlet and through an inertial particle size separator, where the suspended particulate matter in the PM$_{10}$ or PM$_{2.5}$ size ranges is separated for collection on a filter. Figure 2.4 shows a diagram of IVL PM$_{2.5}$ sampler with parts, this is similar to IVL PM$_{10}$ sampler.
2.9 SMOKE STAIN REFLECTOMETER (SSR)

The first step in calculating atmospheric black carbon (black smoke) concentration is to measure the darkness of the smoke stains on aerosol filter. This is carried out using a photo-electric Reflectometer (DETR, 1999). This instrument emits a steady light (high performance LED with maximum emission at 650nm) onto the smoke stain, which is reflected back from the smoke stain to a photo-sensitive element. The electrical response is then amplified to produce a meter reading. The darker the stain, the less light is reflected, so a low meter reading corresponds to a dark surface, and a high reading to a light surface. The reflectometer reads on a scale of 0 (black) to 100 (white).

The reflectometer used in this project is the EEL Model 43D (digital) from Diffusion System of UK (figure 2.5). It has a measuring head, which comprises a source of light (a tungsten lamp) and a photo-sensitive element (a selenium disc). The head fits into a detachable mask which consists of a locating ring with a metal plate. The mask covers all the working area of the element except for an aperture 1.25cm in diameter, through which the stain is measured.
CHAPTER THREE

3.0 MATERIALS AND METHODS

There are usually two major types of concerns to the research scientist with regard to measurement strategies. These are: technical and scientific concerns and a more practical or feasibility concern. Regarding the technical and scientific concerns one is often faced with balancing the sampling time and number of samples (or length of the data series) against the accuracy and risk of not exceeding the above mentioned factors. Another important factor is the amount of data information needed (i.e. sample size) to discard a hypothesis.

The other major concern is of a more practical nature. The number of sampling setups available, the analytical cost, the workload during sample collection and the project funding are all limiting variables that must be taken into account.

The aims of a project or study establish the basis for designing the measurement strategies and since the aim of this study is to understand and describe the measured air pollution situation. The traditional way of doing this is the use of a central outdoor monitoring site to represent the exposure in a population (within a city).

With the help of The National Nuclear Research Institute (NNRI) of Ghana Atomic Energy Commission (GAEC), a temporal central outdoor monitoring site had been located at Ashaiman Senior High School, Ashaiman-Ghana. The gravimetric and black carbon analyses were carried out at the X-ray Fluorescence Analysis (XFA) laboratory of (GAEC).
3.1 STUDY AREA AND MEASUREMENT PERIODS

When selecting a monitoring site, there are a number of parameters to be considered, these include locality, terrain, meteorology, emission sources, possible chemical or physical interference, availability of services and site security. Ashaiman has been chosen for this study based on these factors with the aims and objectives of the study in mind.

Ashaiman is a sprawling "urban slum" located about four kilometres to the north of Tema, the industrial city of Ghana and about 30 km from Accra, the capital city of Ghana. With a land area of about two square kilometers, the estimated population in 2000 was 150,312.

The topography of the area is gently flat and forms part of the Accra-Togo plains. However there are isolated hills in the general area, but even these barely reach 65m high. (TMA 2002).

Temperatures are high throughout the year. March - April is usually the hottest period with temperatures reaching 30°C during the day and 27°C at night. Cooler temperatures occur from May – September with a high of 27 – 29°C during the day and 22 – 24°C in the night. Humidity varies with the seasons with a high of 60 – 80% in the wet season and less than 30% in the dry periods. Measurements were carried out for 90 days between February and May, 2008. The site is about 1.1 km from the central business centre of Ashaiman. The possible emission
sources in the area are mainly domestic or residential burning and the major streets near and within the Ashaiman Township

3.2 SAMPLING EQUIPMENTS AND METHODS

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. Fig 3.2 shows a schematic diagram of the IVL PM$_{2.5}$ Sampler system which is similar to that of IVL PM$_{10}$ sampler, the samplers are about 2.0 m from the ground. 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 filters were weighed before and after sampling using a Sartorius MC-5 micro-gramme sensitive balance in a temperature- and relative humidity-controlled environment. The sampling in this work was done for approximately 24 hours and at a flow rate of approximately 17.0 l/min.
Figure 3.2 Schematic diagram of the IVL PM 2.5 Sampler
3.4 SMOKE STAIN REFLECTOMETER

After the gravimetric analysis to determine the mass concentrations, the filters were examined for black smoke using an EEL 43D smoke Stain Reflectometer - Fig. 2.5, (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 and converted to optical voltage \((U = 0.0777 \times \text{reading})\). Reflectance readings (output voltages readings) were obtained for the aerosol or sample filters, totally black filter and totally white filter.

3.4.1 Preparation of the SSR instrument

Before taking measurements, the measuring head, mask and standard plate of the Reflectometer are cleaned with pure ethanol \((C_2H_5OH)\) and the instrument switched on to warm for more than 15 minutes. The measuring head inserted in the mask is then connected to the SSR central unit after adjusting the LCD meter reading to zero using the zero knob in the front panel of the SSR.

Locating the measuring head over the white standard, the reflectance reading is adjusted to 100.0 by using coarse and fine knobs in the front panel.
For linearity check, the measuring head is moved over the grey standard to ensure that the reading is within the limits given for the standard plate in the manufacturer's manual.

3.4.2 Calibration

The Smoke Stain Reflectometer is calibrated by the manufacturer. For the calibration parameters provided by the manufacturer to be used, reflected light by a white filter (this is set to 8.0) and a totally black filter (set to 0.4) are obtained before evaluating the sample filter.

3.4.3 Measurement of reflectance

With the measuring head tightly attached to the mask, the sample filter is removed from the Petri dish using tweezers and located centrally on the white standard. The reflectance reading is measured from the meter reading on the smoke stain reflectometer. Four additional measurements using the same sample filter is taken (The results are recorded in appendix III and IV)

After every series of five sample filters reading taken, the mask, standard plate and tweezers are cleaned and calibration parameter re-set to 8.0 for a white filter and 0.4 for a totally black filter.
3.5 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 (Model 43D, Diffusion Systems Ltd, London).

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 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 voltage to the black smoke number is:

\[ E = RZ \log \left( \frac{U_{black} - U_{white}}{U_{black} - U_{black,ref}} \right) \]  

(3.2)
where

\[ U_{\text{RZ}0} = \text{output voltage with blank (white) filter (which is set to 8.0 V according to the instructions manual)} \]

\[ U_{\text{RZmax}} = \text{output voltage with totally black filter (set to 0.4 V)} \]

\[ U_{\text{RZ}} = \text{output voltage with sample to be evaluated} \]

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:

\[
C_R = \frac{\ln(1 - (RZ - RZ_0) / kRZ_{\text{max}})}{V}
\]

(3.3)

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

\( RZ_{\text{max}} \) = the black smoke number for a black filter

\( k \) = calibration constant.
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. Regular linearity check was performed by a white/grey standard supplied with the instrument.

3.6 QUALITY CONSIDERATIONS

In this study, a Quality Assurance (QA) and Quality Control (QC) activity covers two main areas, that is, site audits and reflectometer calibration. The site audits ensure that the quality of sampling is maintained. The main operational features of site audits relevant to the measurement of particles are: measurement of sample flow, leak check of each sampler port and installation of flow meter.

Reflectometer calibrations also ensure the consistency and accuracy of the reflectometry measurements.

Due to handling and limits of the measuring equipments, each measurement contains a degree of uncertainty. The major sources of error concerning the sampling and analyses of particulate matter samples include 1) artifacts or contamination of samples, 2) loss of collected aerosol species during sampling or after sampling, 3) sample handling, transport and storage, 4) modification of samples during analyses, and 5) errors in data handling. In order to control and minimize the overall uncertainty caused by these factors, the sampling of PM and weighing of filters were carried out according to a standard operation procedure to assure high quality of sample processing.
The Smoke Stain Reflectometer is calibrated by the manufacturer. For the calibration parameters provided by the manufacturer to be used, reflected light by a white filter (this is set to 8.0) and a totally black filter (set to 0.4) are obtained before evaluating the sample filter. After every series of five sample filters reading taken, the mask, standard plate and tweezers are cleaned and calibration parameter re-set to 8.0 for a white filter and 0.4 for a totally black filter to ensure comparable and reproducible results.

Raw data were first entered on printed field forms and subsequently, typed into computer files which were checked for possible typing errors.
CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1 MASS CONCENTRATIONS (μg m⁻³) AND BLACK CARBON (BC) CONCENTRATIONS (μg m⁻³) IN AMBIENT AIR

For the period of study, the semi-urban background total mass concentration (μg m⁻³) of PM₂.₅ and PM₁₀ collected on the filters varied from day to day.

Table 4.1 gives mean mass concentrations of PM₂.₅ and PM₁₀, black carbon concentration and the percentage black carbon concentration together with their standard deviations and ranges. It should be noted that the standard deviations are not "true" deviations which expresses fluctuations in experimental conditions for the analytical methods. Instead, they are combinations of these and the variations that occur due to changing weather conditions and human activities from one day to another. The relative standard deviation and the detection limit of BC are 0.12% and 0.01μg m⁻³, respectively (Ying et al., 2006). The maximum and the minimum values of these parameters provided in table 4.1 give an indication to how widely they varied from day to day.
<table>
<thead>
<tr>
<th>Property</th>
<th>Maximum</th>
<th>Minimum</th>
<th>Mean</th>
<th>Standard Dev.</th>
</tr>
</thead>
<tbody>
<tr>
<td>PM$_{2.5}$/ $\mu$g m$^{-3}$</td>
<td>46.43</td>
<td>3.85</td>
<td>23.26</td>
<td>12.66</td>
</tr>
<tr>
<td>PM$_{10}$/ $\mu$g m$^{-3}$</td>
<td>293.06</td>
<td>37.10</td>
<td>96.56</td>
<td>49.59</td>
</tr>
<tr>
<td>BC (PM$_{2.5}$)/ $\mu$g m$^{-3}$</td>
<td>4.89</td>
<td>1.67</td>
<td>2.83</td>
<td>0.75</td>
</tr>
<tr>
<td>BC (PM$_{10}$)/ $\mu$g m$^{-3}$</td>
<td>12.44</td>
<td>1.99</td>
<td>3.98</td>
<td>1.81</td>
</tr>
<tr>
<td>%BC (PM$_{2.5}$)</td>
<td>63.14</td>
<td>6.12</td>
<td>18.40</td>
<td>14.52</td>
</tr>
<tr>
<td>%BC (PM$_{10}$)</td>
<td>12.62</td>
<td>1.07</td>
<td>4.86</td>
<td>2.51</td>
</tr>
</tbody>
</table>

Table 4.1 Mass Concentrations ($\mu$g m$^{-3}$), and Black Carbon (BC)

Concentrations ($\mu$g m$^{-3}$) in ambient air in Ashaiman between February and May, 2008.

PM$_{2.5}$ mass concentrations in Ashaiman ranged between 3.85 and 46.43 $\mu$g m$^{-3}$, with a mean of 23.26 $\mu$g m$^{-3}$. The PM$_{10}$ mass concentration is much higher (about
5 times) compared to the fine (PM$_{2.5}$) fraction. The semi-urban background PM$_{10}$ mass concentrations in Ashaiman ranged between 37.10 and 293.06 μg m$^{-3}$, with a mean of 96.56 μg m$^{-3}$. This shows that during the period of study, the area 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 figure 4.1 – 3.
Figure 4.1: \( PM_{2.5} \) and \( PM_{10} \) Mass Concentration
Figure 4.2: PM2.5 Black Carbon Mass Concentration

Concentration (ug/m³)

Date

14/2/2008
22/2/2008
7/3/2008
12/3/2008
16/3/2008
21/3/2008
25/3/2008
30/3/2008
5/4/2008
13/4/2008
19/4/2008
25/4/2008
2/5/2008
12/5/2008
16/5/2008
23/5/2008

BC Conc. in PM2.5
Figure 4.3: PM₁₀ Black Carbon Mass Concentration

Date

Concentration (µg/m³)

0.000
2.000
4.000
6.000
8.000
10.000
12.000
14.000

BC Conc. in PM₁₀
Comparing the result from this work with selection from literature as in Table 4.2 below revealed that both PM$_{2.5}$ and PM$_{10}$ mean values are very high.

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$^{-3}$. 
Comparing the result from this work with selection from literature as in Table 4.2 below revealed that both PM$_{2.5}$ and PM$_{10}$ mean values are very high.

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$\mu$gm$^{-3}$, and the guideline is 10 $\mu$g m$^{-3}$. 
<table>
<thead>
<tr>
<th>Place</th>
<th>Concentration (μg m⁻³)</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Skukuza (South Africa)</td>
<td>9.41 16.2</td>
<td>Maenhaut; 1996</td>
</tr>
<tr>
<td>Prestoriaskop (South Africa)</td>
<td>12.3 19.4</td>
<td>&quot;</td>
</tr>
<tr>
<td>Palmer (South Africa)</td>
<td>18.0 15.2</td>
<td>&quot;</td>
</tr>
<tr>
<td>Watertown, Boston (USA)</td>
<td>17.4 8.6</td>
<td>Chan; 2000</td>
</tr>
<tr>
<td>Long Beach, California (USA)</td>
<td>48.6 22.5</td>
<td>&quot;</td>
</tr>
<tr>
<td>Kashima (Japan)</td>
<td>17.7 17.5</td>
<td>&quot;</td>
</tr>
<tr>
<td>Tapada du Quiterio (Portugal)</td>
<td>18.5 13.1</td>
<td>Alves; 1998</td>
</tr>
<tr>
<td>Calgary (Canada)</td>
<td>11.1 26.3</td>
<td>Cheng; 2000</td>
</tr>
<tr>
<td>Edmonton (Canada)</td>
<td>11.2 19.1</td>
<td>&quot;</td>
</tr>
<tr>
<td>Hinton (Canada)</td>
<td>8.0 17.0</td>
<td>&quot;</td>
</tr>
<tr>
<td>Serowe (Botswana)</td>
<td>10.1 18.4</td>
<td>Moloi; 2002</td>
</tr>
<tr>
<td>Goteborg (Sweden)</td>
<td>7.0 7.2</td>
<td>&quot;</td>
</tr>
<tr>
<td>Kwabenya (Ghana)</td>
<td>4.3 55.4*</td>
<td>Aboh &amp; Ofosu, 2006</td>
</tr>
<tr>
<td>Ashaiman (Ghana)</td>
<td>23.3 96.6</td>
<td>This work</td>
</tr>
</tbody>
</table>

* Value for PM₁₀⁻₂.₅. To get the actual PM₁₀ value, this must be added to PM₂.₅ value.

Table 4.2: Comparison of PM with a selection from literature (Aboh & Ofosu, 2006).
Table 4.3 gives the International air quality standards and guidelines.

<table>
<thead>
<tr>
<th>Particulate Size</th>
<th>Time</th>
<th>Ambient Air Quality Standards, in μg/m³</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>U.S. EPA</td>
</tr>
<tr>
<td>PM$_{10}$</td>
<td>Annual</td>
<td>50</td>
</tr>
<tr>
<td></td>
<td>24hr</td>
<td>150</td>
</tr>
<tr>
<td>PM$_{2.5}$</td>
<td>Annual</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>24hr</td>
<td>65</td>
</tr>
</tbody>
</table>

Table 4.3: INTERNATIONAL AIR QUALITY STANDARDS AND GUIDELINES.
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 & Ofosu, (2006), reported a daily mean PM$_{2.5}$ and PM$_{10}$ concentrations of 4.3 µg/m$^3$ and 59.7 µg/m$^3$ at a site located in Kwabenya (within the same region) during 2005/06 harmattan. These values are 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 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 common in this area also played a major role in the coarse fraction.

Further work should be done on these aerosol samples to identify the sources and the quantities from those sources.

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.

4.2. CONCENTRATION RATIOS OF PM$_{10}$, PM$_{2.5}$ AND BLACK CARBON (BC).

Table 4.4 shows the concentration ratios of PM10, PM2.5 and black carbon.

<table>
<thead>
<tr>
<th>Property</th>
<th>Maximum</th>
<th>Minimum</th>
<th>Mean</th>
<th>Standard Dev.</th>
</tr>
</thead>
<tbody>
<tr>
<td>PM$<em>{2.5}$/PM$</em>{10}$</td>
<td>0.537</td>
<td>0.067</td>
<td>0.300</td>
<td>0.145</td>
</tr>
<tr>
<td>BC/PM$_{2.5}$</td>
<td>0.631</td>
<td>0.061</td>
<td>0.184</td>
<td>0.145</td>
</tr>
<tr>
<td>BC/PM$_{10}$</td>
<td>0.126</td>
<td>0.011</td>
<td>0.049</td>
<td>0.025</td>
</tr>
<tr>
<td>PM$_{10-2.5}$/µg m$^{-3}$</td>
<td>261.810</td>
<td>20.252</td>
<td>73.304</td>
<td>45.136</td>
</tr>
</tbody>
</table>

Table 4.4 Concentration Ratios of PM$_{10}$, PM$_{2.5}$ AND BS.

From 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$_{2.5-10}$ concentrations (PM$_{2.5-10}$, 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 (Table 4.4) gives an indication to how widely these ratios varied from day to day suggest that the ratio is high in some cases (figure 5.5). Maximum PM$_{2.5}$/PM$_{10}$ ratios are often associated with local pollution episodes that are associated to combustion sources (Marcuzzan 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% (Table 4.4). 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.

The daily variations of concentration ratios of PM$_{2.5}$, PM$_{10}$ and BC concentrations are presented in Fig. 4.4-5
Figure 4.4: Black Carbon Fraction of PM$_{2.5}$ and PM$_{10}$
Figure 4.5: Ratios of PM2.5 to PM10

PM<sub>2.5</sub>/PM<sub>10</sub>

DATE

RATIOS OF PM<sub>2.5</sub> TO PM<sub>10</sub>

14/2/2008
22/2/2008
7/3/2008
12/3/2008
16/3/2008
21/3/2008
25/3/2008
30/3/2008
5/4/2008
13/4/2008
19/4/2008
25/4/2008
2/5/2008
12/5/2008
16/4/2008
23/5/2008
The daily variation in $PM_{10-2.5}$ (calculated as difference between $PM_{10}$ and $PM_{2.5}$ concentrations) is shown in figure 4.6.
Figure 4.6 PM10-2.5 Concentration

PM10-2.5/ugm²

Date

14/1/2008
22/1/2008
7/3/2008
12/3/2008
16/3/2008
21/3/2008
25/3/2008
30/3/2008
5/4/2008
13/4/2008
19/4/2008
25/4/2008
25/5/2008
12/5/2008
16/4/2008
23/5/2008
4.3 LIMITATIONS AND SOURCES OF ERROR IN INERTIAL COLLECTION.

There are several inherent sources of error in the impaction process; these include: Particle Shattering, Particle Bounce, Re-entrainment of particles and Wall Loss, Limited Sample Quantity, Sample Loss in Collection, and Poor Particle Resolution for size Analysis. There are errors also associated with the calibration of collection devices and errors in sample analysis.

Large particles (greater than 200 μm) and agglomerates are readily shattered upon impaction, and at the high velocities attained in some impaction devices, particles with diameters as small as two or three micrometers can be shattered. In studies where the number of particles per unit volume of air is of interest, shattering of particles upon collection results in erroneously high results. In size distribution studies there will appear to be fewer larger particles and more small particles than actually exist in the aerosol.

At high impaction velocities, a small fraction of the particles collected may be re-entrained in the air stream. This occurs most often with fragments of large particles that have shattered upon striking the collection surface. Some of the pieces of the shattered particles may be lost from the sample by impacting on the walls of the instrument. A few of the large particles may impact directly on the wall of the instrument.

The small quantity of sample collected also restricts the choice of analytical methods to those with high sensitivity. Care must be taken to preserve all sample
material intact, since with only a few micrograms of sample, the loss of particulate matter becomes significant.

If too much particulate matter collects on the sample collection surface, subsequent particles that impact may be lost by re-entrainment when they strike particles already collected instead of the collection surface. A phenomenon called “ghost depositing” can occur when particles bounce off the collection area and are re-deposited by eddy currents a few millimeters on either side of the sample.

Particles that collect close to and on top of each other will introduce error in concentration and size studies through the inability to distinguish between individual particles and clumps of particles when examined optically. However, if a representative portion of the collected material is properly remounted, these problems can be minimized.

4.4 METEOROLOGY

Air pollution transport, dispersion, transformation and removal are influence by a number of atmospheric processes. Air pollution meteorology is therefore important in managing ambient pollutant concentrations.

Meteorological information is essential in this study since the aim is to understand and describe the measured air pollution situation but unfortunately, there is no Weather Monitoring Station near the sampling site. Also, Ghana Atomic Energy
Commission has no mobile weather monitoring station that could be conveyed to the site. Meteorological factors are most important in governing the concentration variations of particulate matter (Pohjola et al. 2000). The highest particulate matter concentrations are often reported during stable meteorological conditions such as inversion with low wind speeds (Pohjola et al. 2004).

Common parameters such as temperature, wind speed and direction, solar radiation, air pressure, relative humidity and rain, but also, boundary level height and temperature inversions can have an effect on the composition of air. For instance, the direction from which the wind originates determines the influence of upwind sources. Higher wind speeds will increase the ground turbulence and re-suspend particles, and a low boundary level height and especially a temperature inversion will trap the pollutants and increase the concentrations. Also the physical and chemical processes affecting the particles are regulated to a great extent by meteorological factors.
CHAPTER FIVE

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

$\text{mean values of } 23.26 \mu \text{g m}^{-3} \text{ and } 96.56 \mu \text{g m}^{-3} \text{ obtained for PM}_{2.5} \text{ and PM}_{10} \text{ respectively are on a higher side. PM}_{10} \text{ mean value exceeded the WHO guideline and the Ghana Environmental Protection Agency (Ghana EPA) guideline value (70.0 } \mu \text{g m}^{-3} \text{ for 24 hour average and 50 } \mu \text{g m}^{-3} \text{ 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}). \text{ 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} \text{ to PM}_{10} \text{ ratio and the mean of } 73.30 \mu \text{g m}^{-3} \text{ for the coarse fraction (PM}_{10-2.5}) \text{ suggest that most of aerosol measured are in the coarse mode. Also, some of the values from the PM}_{2.5} \text{ to PM}_{10} \text{ 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.
REFERENCES


7. CARB (2002a) California Air Resources Board and Office of Environmental Health Hazard Assessment. Staff Report: Public Hearing to
Consider Amendments to the Ambient Air Quality Standards for Particulate Matter and Sulfates.


52. Tema Municipal Assembly(TMA) data on Ashaiman, 2002.


## APPENDIX

### TEFLOn (FInE PaRtICuLaTE) PM$_{2.5}$ DATA COlLECTION SUMMARY

<table>
<thead>
<tr>
<th>Filter ID</th>
<th>Particulate Mass/g ± 0.0001/g</th>
<th>Sampling Duration/hrs ± 1/hr</th>
<th>Aerosol Volume/m$^3$ ± 1/m$^3$</th>
<th>Mass Conc./µgm$^{-3}$</th>
<th>Date From</th>
<th>Date To</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>ATF001</td>
<td>0.0006</td>
<td>10</td>
<td>13</td>
<td>48 ± 10</td>
<td>2/13/2008</td>
<td>2/14/2008</td>
<td>FR at 16.5 l/min</td>
</tr>
<tr>
<td>ATF002</td>
<td>0.0007</td>
<td>11</td>
<td>17</td>
<td>41 ± 8</td>
<td>2/17/2008</td>
<td>2/18/2008</td>
<td>FR at 16.8 l/min</td>
</tr>
<tr>
<td>ATF003</td>
<td>0.0005</td>
<td>12</td>
<td>16</td>
<td>31 ± 8</td>
<td>2/21/2008</td>
<td>2/22/2008</td>
<td>FR at 17.0 l/min</td>
</tr>
<tr>
<td>ATF004</td>
<td>0.0005</td>
<td>14</td>
<td>13</td>
<td>118 ± 20</td>
<td>2/25/2008</td>
<td>2/26/2008</td>
<td>FR at 16.0 l/min</td>
</tr>
<tr>
<td>ATF005</td>
<td>0.0005</td>
<td>16</td>
<td>13</td>
<td>38 ± 10</td>
<td>3/2/2008</td>
<td>3/3/2008</td>
<td>FR at 18.0 l/min</td>
</tr>
<tr>
<td>ATF006</td>
<td>0.0002</td>
<td>23</td>
<td>21</td>
<td>10 ± 5</td>
<td>3/6/2008</td>
<td>3/7/2008</td>
<td>FR at 16.5 l/min</td>
</tr>
<tr>
<td>ATF007</td>
<td>0.0001</td>
<td>18</td>
<td>15</td>
<td>7 ± 7</td>
<td>3/9/2008</td>
<td>3/10/2008</td>
<td>FR at 16.0 l/min</td>
</tr>
<tr>
<td>ATF008</td>
<td>0.0006</td>
<td>19</td>
<td>21</td>
<td>29 ± 6</td>
<td>3/11/2008</td>
<td>3/12/2008</td>
<td>FR at 16.0 l/min</td>
</tr>
<tr>
<td>ATF009</td>
<td>0.0001</td>
<td>19</td>
<td>17</td>
<td>6 ± 6</td>
<td>3/13/2008</td>
<td>3/14/2008</td>
<td>FR at 18.0 l/min</td>
</tr>
<tr>
<td>ATF010</td>
<td>0.0004</td>
<td>24</td>
<td>22</td>
<td>18 ± 5</td>
<td>3/15/2008</td>
<td>3/16/2008</td>
<td>FR at 16.5 l/min</td>
</tr>
<tr>
<td>ATF011</td>
<td>0.0005</td>
<td>17</td>
<td>16</td>
<td>31 ± 8</td>
<td>3/17/2008</td>
<td>3/18/2008</td>
<td>FR at 17.0 l/min</td>
</tr>
<tr>
<td>ATF012</td>
<td>1E-04</td>
<td>BLANK</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td>BLANK</td>
</tr>
<tr>
<td>ATF013</td>
<td>0.0003</td>
<td>16</td>
<td>15</td>
<td>20 ± 8</td>
<td>3/20/2008</td>
<td>3/21/2008</td>
<td>FR at 17.0 l/min</td>
</tr>
<tr>
<td>ATF014</td>
<td>0.0005</td>
<td>16</td>
<td>14</td>
<td>21 ± 9</td>
<td>3/22/2008</td>
<td>3/23/2008</td>
<td>FR at 16.5 l/min</td>
</tr>
<tr>
<td>ATF015</td>
<td>0.0002</td>
<td>15</td>
<td>14</td>
<td>14 ± 8</td>
<td>3/24/2008</td>
<td>3/25/2008</td>
<td>FR at 16.5 l/min</td>
</tr>
<tr>
<td>ATF016</td>
<td>1E-04</td>
<td>16</td>
<td>15</td>
<td>7 ± 7</td>
<td>3/27/2008</td>
<td>3/28/2008</td>
<td>FR at 17.0 l/min</td>
</tr>
<tr>
<td>ATF017</td>
<td>0.0002</td>
<td>20</td>
<td>17</td>
<td>12 ± 7</td>
<td>3/29/2008</td>
<td>3/30/2008</td>
<td>FR at 16.0 l/min</td>
</tr>
<tr>
<td>ATF018</td>
<td>0.0001</td>
<td>4</td>
<td>3</td>
<td>33 ± 4</td>
<td>3/31/2008</td>
<td>4/1/2008</td>
<td>FR at 15.0 l/min, power out</td>
</tr>
<tr>
<td>ATF019</td>
<td>0.0002</td>
<td>20</td>
<td>19</td>
<td>10 ± 5</td>
<td>4/4/2008</td>
<td>4/5/2008</td>
<td>FR at 18.0 l/min</td>
</tr>
<tr>
<td>ATF020</td>
<td>-0.0002</td>
<td>BLANK</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td>BLANK</td>
</tr>
<tr>
<td>ATF021</td>
<td>1E-04</td>
<td>18</td>
<td>16</td>
<td>6 ± 7</td>
<td>4/6/2008</td>
<td>4/7/2008</td>
<td>FR at 17.0 l/min</td>
</tr>
<tr>
<td>ATF022</td>
<td>0.0008</td>
<td>19</td>
<td>17</td>
<td>35 ± 8</td>
<td>4/12/2008</td>
<td>4/13/2008</td>
<td>FR at 16.5 l/min</td>
</tr>
<tr>
<td>ATF023</td>
<td>0.00045</td>
<td>21</td>
<td>19</td>
<td>24 ± 7</td>
<td>4/16/2008</td>
<td>4/17/2008</td>
<td>FR at 17.0 l/min</td>
</tr>
<tr>
<td>ATF024</td>
<td>1E-04</td>
<td>22</td>
<td>18</td>
<td>6 ± 6</td>
<td>4/18/2008</td>
<td>4/19/2008</td>
<td>FR at 16.5 l/min</td>
</tr>
<tr>
<td>ATF025</td>
<td>5E-05</td>
<td>9</td>
<td>13</td>
<td>4 ± 8</td>
<td>4/21/2008</td>
<td>4/22/2008</td>
<td>FR at 16.0 l/min</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>FR at 16.5 l/min</td>
<td></td>
</tr>
<tr>
<td>--------</td>
<td>--------</td>
<td>--------</td>
<td>--------</td>
<td>--------</td>
<td>--------</td>
<td>-----------------</td>
<td></td>
</tr>
<tr>
<td>ATF026</td>
<td>0.0004</td>
<td>19</td>
<td>16</td>
<td>25 ± 8</td>
<td>4/24/2008</td>
<td>4/25/2008</td>
<td></td>
</tr>
<tr>
<td>ATF027</td>
<td>0.0006</td>
<td>23</td>
<td>19</td>
<td>32 ± 7</td>
<td>4/26/2008</td>
<td>4/27/2008</td>
<td></td>
</tr>
<tr>
<td>ATF028</td>
<td>0.0005</td>
<td>19</td>
<td>17</td>
<td>29 ± 8</td>
<td>4/29/2008</td>
<td>4/30/2008</td>
<td></td>
</tr>
<tr>
<td>ATF029</td>
<td>0.00055</td>
<td>19</td>
<td>16</td>
<td>34 ± 8</td>
<td>5/1/2008</td>
<td>5/2/2008</td>
<td></td>
</tr>
<tr>
<td>ATF030</td>
<td>0.0004</td>
<td>19</td>
<td>17</td>
<td>24 ± 7</td>
<td>5/6/2008</td>
<td>5/7/2008</td>
<td></td>
</tr>
<tr>
<td>ATF031</td>
<td>1E-04</td>
<td>BLANK</td>
<td>0</td>
<td></td>
<td></td>
<td>BLANK</td>
<td></td>
</tr>
<tr>
<td>ATF032</td>
<td>0.0004</td>
<td>17</td>
<td>4</td>
<td>100 ± 60</td>
<td>5/7/2008</td>
<td>5/8/2008</td>
<td></td>
</tr>
<tr>
<td>ATF033</td>
<td>0.0004</td>
<td>18</td>
<td>16</td>
<td>25 ± 8</td>
<td>5/11/2008</td>
<td>5/12/2008</td>
<td></td>
</tr>
<tr>
<td>ATF034</td>
<td>0.00065</td>
<td>19</td>
<td>14</td>
<td>46 ± 10</td>
<td>5/13/2008</td>
<td>5/14/2008</td>
<td></td>
</tr>
<tr>
<td>ATF035</td>
<td>0.0007</td>
<td>20</td>
<td>21</td>
<td>33 ± 8</td>
<td>5/15/2008</td>
<td>5/16/2008</td>
<td></td>
</tr>
<tr>
<td>ATF036</td>
<td>0.00055</td>
<td>17</td>
<td>17</td>
<td>32 ± 8</td>
<td>5/20/2008</td>
<td>5/21/2008</td>
<td></td>
</tr>
<tr>
<td>ATF037</td>
<td>0.00035</td>
<td>16</td>
<td>16</td>
<td>22 ± 8</td>
<td>5/22/2008</td>
<td>5/23/2008</td>
<td></td>
</tr>
</tbody>
</table>

NB: FR : Sampling Flow Rate
l/min : Litre per minute
## APPENDIX II

**TEFLON PM$_{10}$ DATA COLLECTION SUMMARY**

<table>
<thead>
<tr>
<th>Filter ID</th>
<th>Particulate Mass/g ± 0.0001/g</th>
<th>Sampling Duration/hrs ± 1/hr</th>
<th>Aerosol Volume/m$^3$ ± 0.001/m$^3$</th>
<th>Mass Conc./µg/m$^3$</th>
<th>Date From</th>
<th>Date To</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>ATC001</td>
<td>0.0029</td>
<td>10</td>
<td>20.309</td>
<td>143 ± 5</td>
<td>2/13/2008</td>
<td>2/14/2008</td>
<td>FR at 16.7 l/min</td>
</tr>
<tr>
<td>ATC002</td>
<td>0.0037</td>
<td>11</td>
<td>26.482</td>
<td>145 ± 4</td>
<td>2/17/2008</td>
<td>2/18/2008</td>
<td>FR at 17.0 l/min</td>
</tr>
<tr>
<td>ATC003</td>
<td>0.0075</td>
<td>13</td>
<td>25.692</td>
<td>293 ± 4</td>
<td>2/21/2008</td>
<td>2/22/2008</td>
<td>FR at 17.0 l/min</td>
</tr>
<tr>
<td>ATC004</td>
<td>0.0006</td>
<td>14</td>
<td>16.951</td>
<td>38 ± 6</td>
<td>2/25/2008</td>
<td>2/26/2008</td>
<td>FR at 17.0 l/min</td>
</tr>
<tr>
<td>ATC005</td>
<td>0.0027</td>
<td>15</td>
<td>16.498</td>
<td>174 ± 8</td>
<td>3/2/2008</td>
<td>3/3/2008</td>
<td>FR at 17.0 l/min</td>
</tr>
<tr>
<td>ATC006</td>
<td>0.0002</td>
<td>23</td>
<td>17.173</td>
<td>116 ± 6</td>
<td>3/6/2008</td>
<td>3/7/2008</td>
<td>FR at 17.0 l/min</td>
</tr>
<tr>
<td>ATC007</td>
<td>0.0014</td>
<td>18</td>
<td>14.101</td>
<td>99 ± 7</td>
<td>3/9/2008</td>
<td>3/10/2008</td>
<td>FR at 17.0 l/min</td>
</tr>
<tr>
<td>ATC008</td>
<td>0.0018</td>
<td>19</td>
<td>17.994</td>
<td>100 ± 6</td>
<td>3/11/2008</td>
<td>3/12/2008</td>
<td>FR at 17.0 l/min</td>
</tr>
<tr>
<td>ATC009</td>
<td>0.0008</td>
<td>19</td>
<td>14.269</td>
<td>56 ± 7</td>
<td>3/13/2008</td>
<td>3/14/2008</td>
<td>FR at 17.0 l/min</td>
</tr>
<tr>
<td>ATC010</td>
<td>0.0017</td>
<td>24</td>
<td>18.043</td>
<td>94 ± 6</td>
<td>3/15/2008</td>
<td>3/16/2008</td>
<td>FR at 17.0 l/min</td>
</tr>
<tr>
<td>ATC011</td>
<td>0.0015</td>
<td>18</td>
<td>15.209</td>
<td>99 ± 7</td>
<td>3/17/2008</td>
<td>3/18/2008</td>
<td>FR at 18.7 l/min</td>
</tr>
<tr>
<td>ATC012</td>
<td>0 BLANK</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>BLANK</td>
</tr>
<tr>
<td>ATC013</td>
<td>0.0012</td>
<td>16</td>
<td>24.164</td>
<td>50 ± 4</td>
<td>3/20/2008</td>
<td>3/21/2008</td>
<td>FR at 15.5 l/min</td>
</tr>
<tr>
<td>ATC015</td>
<td>0.0017</td>
<td>15</td>
<td>26.57</td>
<td>66 ± 4</td>
<td>3/24/2008</td>
<td>3/25/2008</td>
<td>FR at 17.5 l/min</td>
</tr>
<tr>
<td>ATC016</td>
<td>0.0019</td>
<td>16</td>
<td>26.281</td>
<td>72 ± 4</td>
<td>3/27/2008</td>
<td>3/28/2008</td>
<td>FR at 17.0 l/min</td>
</tr>
<tr>
<td>ATC017</td>
<td>0.0038</td>
<td>20</td>
<td>31.686</td>
<td>120 ± 3</td>
<td>3/29/2008</td>
<td>3/30/2008</td>
<td>FR at 18.7 l/min</td>
</tr>
<tr>
<td>ATC018</td>
<td>0.0003</td>
<td>4</td>
<td>4.748</td>
<td>63 ± 20</td>
<td>3/31/2008</td>
<td>4/1/2008</td>
<td>FR at 16.0 l/min, Power Out</td>
</tr>
<tr>
<td>ATC019</td>
<td>0.0018</td>
<td>20</td>
<td>23.653</td>
<td>76 ± 4</td>
<td>4/4/2008</td>
<td>4/5/2008</td>
<td>FR at 17.0 l/min</td>
</tr>
<tr>
<td>ATC020</td>
<td>-1E-04</td>
<td>BLANK</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>BLANK</td>
</tr>
<tr>
<td>ATC021</td>
<td>0.001</td>
<td>18</td>
<td>20.594</td>
<td>49 ± 5</td>
<td>4/6/2008</td>
<td>4/7/2008</td>
<td>FR at 17.0 l/min</td>
</tr>
<tr>
<td>ATC022</td>
<td>0.0023</td>
<td>19</td>
<td>20.533</td>
<td>112 ± 5</td>
<td>4/12/2008</td>
<td>4/13/2008</td>
<td>FR at 16.0 l/min</td>
</tr>
<tr>
<td>ATC023</td>
<td>0.0016</td>
<td>21</td>
<td>23.472</td>
<td>68 ± 4</td>
<td>4/16/2008</td>
<td>4/17/2008</td>
<td>FR at 16.7 l/min</td>
</tr>
<tr>
<td>ATC024</td>
<td>0.0003</td>
<td>22</td>
<td>26.108</td>
<td>69 ± 4</td>
<td>4/18/2008</td>
<td>4/19/2008</td>
<td>FR at 17.0 l/min</td>
</tr>
<tr>
<td>ATC025</td>
<td>0.0007</td>
<td>9</td>
<td>18.886</td>
<td>37 ± 5</td>
<td>4/21/2008</td>
<td>4/22/2008</td>
<td>FR at 16.7 l/min</td>
</tr>
<tr>
<td>ATC026</td>
<td>0.0022</td>
<td>19</td>
<td>18.815</td>
<td>117 ± 5</td>
<td>4/24/2008</td>
<td>4/25/2008</td>
<td>FR at 16.0 l/min</td>
</tr>
<tr>
<td>ATC027</td>
<td>0.0011</td>
<td>23</td>
<td>25</td>
<td>44 ± 4</td>
<td>4/26/2008</td>
<td>4/27/2008</td>
<td>FR at 17.5 l/min</td>
</tr>
<tr>
<td>ATC028</td>
<td>0.00275</td>
<td>19</td>
<td>22.79</td>
<td>121 ± 4</td>
<td>4/29/2008</td>
<td>4/30/2008</td>
<td>FR at 17.0 l/min</td>
</tr>
</tbody>
</table>

*Power Out*
<table>
<thead>
<tr>
<th>ATC029</th>
<th>0.0026</th>
<th>19</th>
<th>22.019</th>
<th>118 ± 5</th>
<th>5/1/2008</th>
<th>5/2/2008</th>
<th>FR at 17.0 L/min</th>
</tr>
</thead>
<tbody>
<tr>
<td>ATC030</td>
<td>0.0017</td>
<td>19</td>
<td>19.902</td>
<td>85 ± 5</td>
<td>5/6/2008</td>
<td>5/7/2008</td>
<td>FR at 16.0 L/min</td>
</tr>
<tr>
<td>ATC031</td>
<td>0</td>
<td>BLANK</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>BLANK</td>
</tr>
<tr>
<td>ATC032</td>
<td>0.0003</td>
<td>17</td>
<td>5.628</td>
<td>53 ± 20</td>
<td>5/7/2008</td>
<td>5/8/2008</td>
<td>FR at 17.0 L/min</td>
</tr>
<tr>
<td>ATC033</td>
<td>0.00095</td>
<td>18</td>
<td>20.387</td>
<td>47 ± 5</td>
<td>5/11/2008</td>
<td>5/12/2008</td>
<td>FR at 17.0 L/min</td>
</tr>
<tr>
<td>ATC034</td>
<td>0.0023</td>
<td>19</td>
<td>18.758</td>
<td>122 ± 8</td>
<td>5/13/2008</td>
<td>5/14/2008</td>
<td>FR at 16.7 L/min</td>
</tr>
<tr>
<td>ATC035</td>
<td>0.00185</td>
<td>20</td>
<td>25.834</td>
<td>72 ± 4</td>
<td>5/15/2008</td>
<td>5/16/2008</td>
<td>FR at 17.5 L/min</td>
</tr>
<tr>
<td>ATC036</td>
<td>0.0015</td>
<td>18</td>
<td>21.924</td>
<td>68 ± 5</td>
<td>5/20/2008</td>
<td>5/21/2008</td>
<td>FR at 16.7 L/min</td>
</tr>
<tr>
<td>ATC037</td>
<td>0.0009</td>
<td>16</td>
<td>21.364</td>
<td>42 ± 5</td>
<td>5/22/2008</td>
<td>5/23/2008</td>
<td>FR at 16.7 L/min</td>
</tr>
</tbody>
</table>

NB: FR : Sampling Flow Rate
l/min : Litre per minute
## APPENDIX III

**TEFLON (FINE PARTICULATE) PM$_{2.5}$ AVERAGE OUTPUT VOLTAGE**

*(SMOKE STAIN REFLECTOMETER READINGS)*

<table>
<thead>
<tr>
<th>FILTER ID</th>
<th>OUTPUT VOLTAGE ± 0.1V</th>
</tr>
</thead>
<tbody>
<tr>
<td>ATF001</td>
<td>0.8</td>
</tr>
<tr>
<td>ATF002</td>
<td>1.1</td>
</tr>
<tr>
<td>ATF003</td>
<td>1.6</td>
</tr>
<tr>
<td>ATF004</td>
<td>1.7</td>
</tr>
<tr>
<td>ATF005</td>
<td>0.9</td>
</tr>
<tr>
<td>ATF006</td>
<td>1.0</td>
</tr>
<tr>
<td>ATF007</td>
<td>1.1</td>
</tr>
<tr>
<td>ATF008</td>
<td>1.2</td>
</tr>
<tr>
<td>ATF009</td>
<td>1.2</td>
</tr>
<tr>
<td>ATF010</td>
<td>1.4</td>
</tr>
<tr>
<td>ATF011</td>
<td>0.9</td>
</tr>
<tr>
<td>ATF012</td>
<td>3.9</td>
</tr>
<tr>
<td>ATF013</td>
<td>1.3</td>
</tr>
<tr>
<td>ATF014</td>
<td>1.8</td>
</tr>
<tr>
<td>ATF015</td>
<td>1.0</td>
</tr>
<tr>
<td>ATF016</td>
<td>1.8</td>
</tr>
<tr>
<td>ATF017</td>
<td>1.2</td>
</tr>
<tr>
<td>ATF018</td>
<td>8.0</td>
</tr>
<tr>
<td>ATF019</td>
<td>0.8</td>
</tr>
<tr>
<td>ATF020</td>
<td>8.0</td>
</tr>
<tr>
<td>ATF021</td>
<td>1.2</td>
</tr>
<tr>
<td>ATF022</td>
<td>1.4</td>
</tr>
<tr>
<td>ATF023</td>
<td>1.2</td>
</tr>
<tr>
<td>ATF024</td>
<td>1.1</td>
</tr>
<tr>
<td>ATF025</td>
<td>1.7</td>
</tr>
<tr>
<td>ATF026</td>
<td>0.6</td>
</tr>
<tr>
<td>ATF027</td>
<td>0.5</td>
</tr>
<tr>
<td>ATF028</td>
<td>0.8</td>
</tr>
<tr>
<td>ATF029</td>
<td>1.1</td>
</tr>
<tr>
<td>ATF030</td>
<td>0.9</td>
</tr>
<tr>
<td>ATF031</td>
<td>8.0</td>
</tr>
<tr>
<td>ATF032</td>
<td>3.7</td>
</tr>
<tr>
<td>ATF033</td>
<td>1.1</td>
</tr>
<tr>
<td>ATF034</td>
<td>1.2</td>
</tr>
<tr>
<td>ATF035</td>
<td>0.7</td>
</tr>
<tr>
<td>ATF036</td>
<td>0.9</td>
</tr>
<tr>
<td>ATF037</td>
<td>1.1</td>
</tr>
</tbody>
</table>
## APPENDIX IV

### Teflon PM<sub>10</sub> Average Output Voltages

**Smoke Stain Reflectometer Readings**

<table>
<thead>
<tr>
<th>FILTER ID</th>
<th>OUTPUT VOLTAGE ± 0.1V</th>
</tr>
</thead>
<tbody>
<tr>
<td>ATC001</td>
<td>1.9</td>
</tr>
<tr>
<td>ATC002</td>
<td>2.1</td>
</tr>
<tr>
<td>ATC003</td>
<td>2.8</td>
</tr>
<tr>
<td>ATC004</td>
<td>Broken</td>
</tr>
<tr>
<td>ATC005</td>
<td>2.7</td>
</tr>
<tr>
<td>ATC006</td>
<td>3.3</td>
</tr>
<tr>
<td>ATC007</td>
<td>3.6</td>
</tr>
<tr>
<td>ATC008</td>
<td>3.5</td>
</tr>
<tr>
<td>ATC009</td>
<td>2.9</td>
</tr>
<tr>
<td>ATC010</td>
<td>4.2</td>
</tr>
<tr>
<td>ATC011</td>
<td>Broken</td>
</tr>
<tr>
<td>ATC012</td>
<td>8.0</td>
</tr>
<tr>
<td>ATC013</td>
<td>3.4</td>
</tr>
<tr>
<td>ATC014</td>
<td>4.0</td>
</tr>
<tr>
<td>ATC015</td>
<td>2.0</td>
</tr>
<tr>
<td>ATC016</td>
<td>2.8</td>
</tr>
<tr>
<td>ATC017</td>
<td>2.6</td>
</tr>
<tr>
<td>ATC018</td>
<td>5.8</td>
</tr>
<tr>
<td>ATC019</td>
<td>2.0</td>
</tr>
<tr>
<td>ATC020</td>
<td>8.0</td>
</tr>
<tr>
<td>ATC021</td>
<td>2.8</td>
</tr>
<tr>
<td>ATC022</td>
<td>3.3</td>
</tr>
<tr>
<td>ATC023</td>
<td>3.0</td>
</tr>
<tr>
<td>ATC024</td>
<td>3.2</td>
</tr>
<tr>
<td>ATC025</td>
<td>4.4</td>
</tr>
<tr>
<td>ATC026</td>
<td>2.8</td>
</tr>
<tr>
<td>ATC027</td>
<td>2.2</td>
</tr>
<tr>
<td>ATC028</td>
<td>3.1</td>
</tr>
<tr>
<td>ATC029</td>
<td>3.0</td>
</tr>
<tr>
<td>ATC030</td>
<td>3.1</td>
</tr>
<tr>
<td>ATC031</td>
<td>8.0</td>
</tr>
<tr>
<td>ATC032</td>
<td>5.2</td>
</tr>
<tr>
<td>ATC033</td>
<td>2.8</td>
</tr>
<tr>
<td>ATC034</td>
<td>3.0</td>
</tr>
<tr>
<td>ATC035</td>
<td>1.8</td>
</tr>
<tr>
<td>ATC036</td>
<td>2.6</td>
</tr>
<tr>
<td>ATC037</td>
<td>3.2</td>
</tr>
</tbody>
</table>