UNIVERSITY OF CAPE COAST

PARTICULATE MATTER POLLUTION IN THE TAKORADI HARBOUR INDUSTRIAL AREA

BY

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DECLARATION

Candidate's Declaration

I hereby declare that this dissertation is the result of my own original work and that no part of it has been presented for another degree in this university or elsewhere.

Candidate's Signature: …………………………. Date: ………………….

Name: Joseph Mensah

Supervisor's Declaration

I hereby declare that the preparation and presentation of the dissertation were supervised in accordance with the guidelines on supervision of dissertation laid down by the University of Cape Coast.

Supervisor's Signature: ………………………… Date: ………………….

Name: Dr. Patrick K. Agbesinyale

ABSTRACT

Air pollution is the introduction into the atmosphere of chemicals, particulate matter or biological materials that cause harm or discomfort to humans or other living organisms, or damage the natural environment. Particulate matter smaller than 10μm, can settle in the bronchi and lungs and cause health problems.

The study investigated and evaluated the release of particulate matter (both TSP and PM_{10}) from industrial activities within the Takoradi Port Industrial Area which is seen as a major source of air pollution. The Total Quality Management model which derives its concept from the Deming cycle was adopted in the conceptual framework.

Samples of ambient particulates were collected from eleven designated points within the study area. Altogether 176 values were recorded from the TSP and PM_{10} measurements for the dry and wet seasons monitoring exercises. The study sought to determine whether the mean dust emission levels for the various sampling locations were within the EPA maximum permissible guideline limits. By the decision rule, there were significant differences in the mean TSP and PM_{10} values and their corresponding permissible limits for all data monitored. These differences called for concerted effort from all stakeholders to address the dust pollution issue.

Companies operating within the harbour area must take pragmatic measures to minimize their particulate matter emissions into the atmosphere. Adopting and implementing a management system consistent with ISO 14001 could possibly bring the needed transformation.

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I could not have done this without the support of my company - Ghacem - which is now striving for excellence in its environmental performance. This is another clear demonstration of the company's commitment towards ensuring environmentally friendly working atmosphere. Our effort in becoming ISO 14001 certified by the end of year 2007 would be a reality.

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DEDICATION

To management and staff of Ghacem, the Nation’s Builder trusted for more than forty years.

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LIST OF ACRONYMS

ARSCP: Africa Roundtable on Sustainable Consumption and Production

CP : Cleaner Production

EMP : Environmental Management Program

EMS : Environmental Management System

EPA : Environmental Protection Agency

GPHA : Ghana Ports and Harbours Authority

NCPC : National Cleaner Production Centre

PM_{10} : Particulate Matter with diameter less than 10 microns

TSP : Total Suspended particulate

CHAPTER ONE

INTRODUCTION

Background to the study

How does the air taste, feel, smell, and look in our homes or neighbourhood? Chances are that wherever we find ourselves, the air around us is contaminated to some degree. Smoke, haze, dust, odours, corrosive gases, noise and toxic compounds are present nearly everywhere, even in the most remote, pristine wilderness (Cunninghan & Sagio, 1979).

Air pollution is the introduction into the atmosphere of chemicals, particulate matter or biological materials that cause harm or discomfort to humans or other living organisms, or damage the natural environment. The most important Air Pollutants with the greatest impact on human health are Ozone, Carbon Monoxide, Airborne Particulates, Nitrogen Oxides, Lead, Sulphur Oxides, Diesel Emissions (which include Polycyclic Aromatic Hydrocarbon (PAHs) that are associated with tumor formation and cancer) (Kleinman, 2008). Air pollution is generally the most widespread and obvious kind of environmental problem. According to the United States Environmental Protection Agency (US EPA), some 7.5 megatons of Total Suspended Particulate, 21.5 megatons Sulphur Oxides, 79 megatons of Carbon Monoxide, 20.3 megatons of Nitrogen Oxides and 18.6 megatons of Volatile Organic Compounds are released into the atmosphere each year in the United States by human activities. Total worldwide emissions of these pollutants are around 2 billion metric tons per year. The air in a typical industrial city can contain unhealthy concentrations of hundreds of different toxic substances; indoors can be even worse.

Over the past twenty years, air quality has improved appreciably in most cities in Western Europe, North America, and Japan. This is an encouraging example of improvement in environmental conditions. Mankind's success in controlling some of the most serious air pollutants gives us hope for similar progress in other environmental problems. But while developed countries have been making progress, air quality in the developing world including Africa has not improved. This is especially so in countries such as Ghana, where air pollution often exceeds World Health Organization standards. It is however, believed that developing countries have borne far worse consequences of industrialization than the Northern countries.

A recent study by Rotstayn and Lohmann (2002) revealed that sulphate aerosols formed upon oxidation of sulphur dioxide emissions from industries in North America and Europe may have been responsible for causing severe droughts in the Sahel region of Africa in the 1980s. Precipitation in this region has fallen by between 20 and 50 per cent in the last 30 years. Also, these emissions may have led to a greater rainfall in Australia as the tropical rain belt shifted southwards. On the other hand, dust storms from Africa's arid Sahelian region, which can rise up to four kilometers into the sky, travel across the Atlantic Ocean to Florida and put about 500 million to 1 billion tonnes of dust into the atmosphere. The incidence of dust clouds reaching Florida has increased since the drought in the Sahel region.

Particulate Matter or Particulates are tiny particles of solid or liquid suspended in air. In contrast, aerosol refers to particles and the gas or air together. The biggest natural sources of particulates are dust storms, volcanoes, and forest and grassland fires. Sea spray is also a large source of particles though most of these fall back to the ocean close to where they were emitted. Particulate matter may also be generated by pollen, bacteria, viruses, fungi, mold, yeast and soil from erosion. Emissions from vegetation and marine organisms form two percent of secondary aerosols in the atmosphere.

About 90% of airborne aerosols occur naturally. Overall, humans are responsible for roughly 10% of the aerosols, and these originate from large stationary sources (industrial processes, thermal power plants, and municipal incinerators), small stationary sources (households and small commercial boilers) and mobile sources (traffic).

Primary aerosols are emitted directly as fine particles, such as smoke from bush or forest fires, soot from burning fossil fuels in industries, vehicles, trains, ships and airplanes, airborne dust and sea-salt particles produced when sea spray dries out, ash and gas from volcanic eruptions, carbon monoxide gas from motor vehicle exhaust and dust released from factories. Secondary aerosols are products from gaseous precursors in which chemical reactions in the air converts the primary gaseous pollutants – like sulphur dioxide (emitted naturally by decay of plant or animal matter) dissolving in cloud droplets to form sulphrous acid, and undergoing oxidation to form sulphuric acid and again undergoing further photochemical oxidation in the presence of water vapour or ammonia to form sulphate particles for instance (Schwartz, 1989).

Airborne Particulate Matter can be characterized by their physical attributes and chemical composition. While physical attributes influence the transport and deposition behaviour their impact on health is also influenced by the chemical composition. Physical attributes include mass concentration and size distribution characteristics. Ambient levels of mass concentration are measured in micrograms per cubic metre ($\mu g/m^3$), while size attributes are most frequently measured in aerodynamic diameter. Particles can range in size from 0.005–500 micrometers or microns (µm), which is equal to one-millionth (10-6) of a meter.

Particles less than 2.5µm in diameter are known as "fine" particles; those larger than 2.5µm are known as "coarse" particles. Fine particles with diameters of less than 1µm move like gases. Because of their low settling velocities, fine particles may be transported 1,000 kilometres or more from their source. Under the influence of gravity, larger particles do not remain suspended and tend to settle out of the air, sometimes creating localized areas of high particle disposition.

Total Suspended Particulate Matter (TSP) refers to all particles in the atmosphere and includes a proportion of particles that may not be able to enter the human respiratory tract. TSP was the first indicator used to represent suspended particles in the ambient air and was not found to be a good indicator of health-related exposure. TSP is measured by a high volume gravimetric sampler that collects suspended particles ranging up to 45µm in diameter in the US, and up to 160µm in Europe on a glass fibre filter. TSP sampling and TSP-based standards were used in the US until 1987. Several countries in Central and Eastern Europe, Latin America and Asia including Ghana still monitor and set standards based on measurements of TSP.

In July 1987, the US EPA began using a new indicator, PM_{10}, which includes only those particles with aerodynamic diameter smaller than 10µm. This fraction of TSP is responsible for most of the adverse human health effects of particulate matter because of the particles' ability to reach the lower regions of the respiratory tract. Recent data suggests that particles 2.5µm or smaller may pose the greatest threat to human health because, for the same mass, they absorb more toxic and carcinogenic compounds than larger particles and penetrate more easily deep into the lungs. Most sophisticated studies suggest that fine particulates are the sole factor accounting for health damage leading to excess mortality and morbidity associated with high levels of exposure to fine particulates while exposure to coarse particulates have little or no independent effect.

To better address the potential health problems associated with these tiny particles, the US EPA issues National Ambient Air Quality Standards (NAAQS) for particulate matter and other pollutants. US EPA first issued standards for particulate matter in 1971; and revised the standards in 1987 and 1997. In September 2006, the US EPA revised the 1997 standards to address two categories of particle pollution: fine particles ($PM_{2.5}$) which are 2.5 micrometers in diameter and smaller; and inhalable coarse particles (PM_{10}) which are smaller than 10 micrometers and larger than 2.5 micrometers (US EPA, 2006).

PM_{10} and $PM_{2.5}$ are sampled using two types of instruments: (i) a high volume sampler with a size selective inlet using a quartz filter; or (ii) a dichotomous sampler that operates at a slower flow rate, separating on a Teflon filter particles smaller than 2.5µm, and sizes between 2.5 and 10µm. Currently, no generally accepted conversion method has yet been devised for TSP and $PM_{10,}$ it could constitute between 35-89% (Querol et al, 2000; Fang et al, 2000; US EPA, 1982). According to European Union (EU) directives on air quality the TSP concentration in the ambient air can be calculated TSP = 1.2 x PM_{10} (EEC, 1989).

In light of emerging evidence of the health impacts of fine particulates, the US EPA has defined the US ambient standards for airborne particulates in terms of fine particulates. Almost all fine particulates are generated as a result of combustion processes including fossil fuel burning for steam generation, heating and household cooking, agricultural field burning, diesel-fueled engine combustion and various industrial processes. Emissions from these anthropogenic sources tend to be in fine fractions, however, some industrial and other processes which produce large amounts of dust, such as cement manufacturing, mining, stone crushing and flour milling tend to generate particles which are larger than 1µm and mostly larger than 2.5µm.

The respiratory system is the major route of entry for airborne particulates. The deposition of particulates in different parts of the human respiratory system depends on the particle size, shape, concentration, and the individual breathing pattern (mouth or nose breathing), while the effect on the human organism is also influenced by the chemical composition of the particles, the duration of exposure, and individual susceptibility. The effect of inhaling particulate matter has been widely studied in humans and animals and includes asthma, lung cancer, cardiovascular issues, and premature death. The size of the particle is a main determinant of where in the respiratory tract the particle will come to rest when inhaled. Because of the size of the particle, they can penetrate the deepest part of the lungs. Larger particles are generally filtered in the nose and throat and do not cause problems, but particulate matter smaller than 10µm, can settle in the bronchi and lungs and cause health problems. The 10µm 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 2.5µm, tend to penetrate into the gas-exchange regions of the lung, and very small particles (less than 100 nanometers) may pass through the lungs to affect other organs.

One study has indicated that $PM_{2.5}$ leads to high plaque deposits in arteries, causing vascular inflammation and atherosclerosis—a hardening of the arteries that reduces elasticity, which can lead to heart attacks and other cardiovascular problems (Pope et al., 2002). Researchers suggest that even short-term exposure at elevated concentrations could significantly contribute to heart disease. The smallest particles, less than 100 nanometers, sometimes called nanoparticles or ultrafine particles (UFP or UP), may be even more damaging to the cardiovascular system. There is evidence that particles smaller than 100 nanometers can pass through cell membranes and migrate into other organs, including the brain. It has been suggested that particulate matter can cause similar brain damage as that found in Alzheimer patients.

Particles emitted from modern diesel engines (commonly referred to as Diesel Particulate Matter or DPM) are typically in the size range of 100 nanometers (0.1μm). In addition, these soot particles also carry carcinogenic components like benzopyrenes adsorbed on their surface. Clinical, epidemiological and toxicological sources are used to estimate the mortality and morbidity effect(s) of short- and long-term exposure of various particulate concentration levels. Several studies have found statistically significant relationships between high short-term ambient particulate concentrations and excess mortality in London and elsewhere. The estimated 4,000 excess deaths in the London metropolitan area in December, 1952, were associated with BS measurements equivalent to 4,000$\mu g/m^3$ maximum daily average ambient concentration of particulates (Schwartz & Dockery, 1992). Particulate matter pollution is estimated to cause 22,000-52,000 deaths per year in the United States from 2000 and 200,000 deaths per year in Europe (Mokdad et al, 2004).

Apart from the health effects associated with particulate matter, mineral constituents of transcontinental dust present an added hazard. Fine iron particles, which give the reddish tinge to the African dust, can generate hydroxyl radicals on the lung surface, which can scar lung tissue over time and decrease its effectiveness. Another important feature of transcontinental dust clouds is the microbes they transport. Initially it was believed that ocean distances were too large for bacteria to survive, but research points that intercontinental dust may transmit viable pathogens. In thick clouds of dust, the ultra violet exposure at the bottom can be just half of that at the upper surface, so microbes in the lower layer can be protected and can survive the transport. Pathogens carried in dust can cause skin infections such as rashes and open sores, and may affect crops like cotton, peaches and rice. Indirectly, dust aerosols can impact nutrition by reducing crop yields—through erosion of soil nutrients and by shading crops from needed ultra violet light to inhibit or obstruct photosynthesis and gas exchange. Lifetimes of most anthropogenic aerosols are in the range of 5 to 10 days. If aerosols are mostly confined to an altitude of one kilometre, they can travel about a thousand kilometres in so many days (Singh, 2002).

Heavy metals, which may be present in particulates when deposited in the soil, inhibit the process in soil that converts nutrients to plants in an accessible form. This, combined with particulates on leaves may contribute to the reduction of plant growth and yield by clogging pores and reducing light interception. Dust particles are abrasive to mechanical equipment and may cause damage to electronic equipment such as computers. Iron and steel in coming into contact with dust particles rust quickly. Silverwares are perpetually tarnished. Dust also has the potential of soiling materials and buildings, with additional cost of cleaning and repainting.

Particulate emissions have their greatest impact on terrestrial ecosystems in the vicinity of emission sources. Ecological alterations may be the result of particulate emissions that include toxic elements. Further, the accumulation of particulate emissions around urban areas and the transport of fine particles across regions frequently reduce visibility. The presence of fine particulates and reduced visibility may cause light scattering, or atmospheric haze. Reduced visibility adversely affects transportation safety, property values, and aesthetics.

A potentially more important impact of aerosol on clouds and climate is that they can serve as a source of cloud condensation nuclei (CCN) and thereby alter the concentration of cloud droplets. Twomey (1974) first pointed out that increasing pollution results in greater CCN concentrations and greater numbers of cloud droplets, which, in turn, increase the reflectance of clouds. Subsequently, Twomey (1977) showed that this effect was most influential for optically thin clouds or clouds having shallow depths. Optically thicker clouds, he argued, are already very bright, and are therefore susceptible to increased absorption by the presence of dirty aerosol. Subsequently, Twomey et al. (1984) presented observational and theoretical evidence indicating that the absorption effect of aerosols is small and the enhanced albedo effect plays a dominant role on global climate. They argued that the enhanced cloud albedo has a magnitude comparable to that of greenhouse warming and acts to cool the atmosphere.

Kaufman et al. (1991) concluded that although coal and oil emit 120 times as many CO_2 molecules as SO_2 molecules, each SO_2 molecule is 50-1100 times more effective in cooling the atmosphere than each CO_2 molecule is in warming it. This is by virtue of the SO_2 molecules' contribution to CCN production and enhanced cloud albedo. In general, an increase in cloud reflectance due to enhanced CCN concentration does not appreciably affect infrared radiation but does reflect more incoming solar radiation which results in a net cooling effect. Moreover, an increase in CCN concentration can reduce drizzle and rain production.

The most frequently used reference guidelines for air quality are those of the World Health Organization (WHO), the EU and the standards of the US EPA (Table 1). Based on clinical, toxicological and epidemiological evidence, these guideline values of ambient particulate concentrations were established by determining concentrations with the lowest-observed-adverse-effect (implicitly accepting the notion that a lower threshold exists under which no adverse human health effects can be detected), adjusted by an arbitrary margin of safety factor to allow for uncertainties in extrapolation from animals to humans and from small groups of humans to larger populations. WHO guidelines are based only on health considerations. Standards determined by the EU and US EPA also reflect the technological feasibility of attainment. In the EU, a prolonged consultation and legislative decision-making processes took into account the environmental conditions and the economic and social development of the various regions and countries, and also acknowledged a phased approach to compliance. The main objective of air quality guidelines and standards is the protection of human health. Since PM_{10} particulates are more likely to cause adverse health effects than in coarse form, guidelines and standards referring to fine particulate concentrations are preferred to those referring to total suspended particulates including very coarse particulate concentrations. Scientific studies provide ample evidence of the relationship between exposure to short-term and long-term ambient particulate concentrations and human mortality and morbidity effects. However, the dose-response mechanism is not yet fully understood.

Table1: Reference standards and guidelines for average ambient particulate concentration μg/m³

Standard	Long-term (annual)			Short-term (24 hours)		
	PM_{10}	BS[1]	TSP	PM_{10}	BS[1]	TSP
EU limit values		80	150		250	300
EU guide values		40-60			100-150	
US EPA standards	50			150		
WHO guidelines		40-60	60-90		100-150	150-230
WHO guidelines for Europe		50		70	125	120
Ghana EPA guidelines			75	70		230

1 Converted to μg/Nm³ measure

Source: European Community (1992)

Air pollutant emission factors are representative values that attempt to relate the quantity of a pollutant released to the ambient air with an activity associated with the release of that pollutant. These factors are usually expressed as the weight of pollutant divided by a unit weight, volume, distance, or duration of the activity emitting the pollutant (e.g. kilograms of particulate emitted per megagram of coal burned). Such factors facilitate estimation of emissions from various sources of air pollution. In most cases, these factors are simply averages of all available data of acceptable quality, and are generally assumed to be representative of long-term average. The US EPA has published compilations of air pollutant emission factors for a multitude of industrial sources (US EPA, 1995).

In Ghana, air pollution results from industrial activities such as mining, quarrying, manufacturing, thermal power generation, smoke from vehicles, dusty roads, bush burning, refuse burning, firewood burning, road construction, land degradation, eroded land surfaces, etc. In some areas, poverty and rapid urbanization have combined to create horrible environmental conditions especially in slums and shantytowns. Suburbs like Sodom and Gomorrah in Accra, New Town in Tema and New Takoradi in Takoradi are examples of areas in Ghana with high population density, lacking basic amenities like sewers, continuous running water and drainage systems. These areas easily act as diffuse sources of air pollution, particularly where poor quality fuels are burned in household stoves. The absence of vegetation cover, emissions from industrial activities, vehicular emissions, and abandoned garbage heaps are the major components of air pollution.

Much as the individual is more likely inclined to the principle of the tragedy of the commons, businesses and corporate organizations have moral and civil obligation in more specific terms towards the communities in which they operate and to a large extent the country as a whole. Organizations of all kinds are increasingly concerned and determined to achieve and demonstrate a high level of environmental performance and stewardship. This is because the pressure on businesses to "clean up the act" is being exerted from a number of different sources. Environmentalism is gradually taking roots in Ghana and pressure is being put on corporate entities to act responsibly. Most corporate organizations have accepted the challenges and have put in place measures to control and manage environmental pollutants from their operations not entirely as a result of compliance to statutory regulations but also as a strategy for gaining competitive advantage and improved public image.

Study area

The study assessed and evaluated the release of particulate matter (both TSP and PM_{10}) from industrial activities within the Takoradi Port Industrial Area. The Takoradi Port Industrial Area is located in the Shama Ahanta East Metropolis in the Western Region of Ghana, (Plate 3). It covers an area of 200,000 square metres.

The harbour area comprises the harbour itself, Ghacem Limited, Takoradi Flour Mills Limited, Ghana Bauxite Company, Ghana Manganese Company, Shell Bitumen plant and Total Bitumen plant. The area adjoins the sea to the South. The nearest residential settlements are New Takoradi to the North East and Chapel Hill and Beach Road to the North and North West respectively.

Ghacem Limited operates a grinding facility that produces 750,000 tonnes of cement annually using clinker, gypsum and limestone as raw materials (Ghacem EMP, 2005). Clinker and gypsum are imported and delivered through the Takoradi harbour by a fleet of barges and belt conveying system. The plant consumes 31,500MWh of electric energy and has particulate matter pollution as the most significant environmental aspect.

Ghana Bauxite Company (GBC) operates a loading facility east of Ghacem using a system of belt conveyors to discharge bauxite material into barges for onward transfer into cargo ship (GBC EMP, 2004). Some 800,000 tonnes of bauxite transported either by rail or road are exported annually and the significant environmental aspect like Ghacem is dust emission.

The Ghana Manganese Company (GMC) also operates a loading facility inside the port area and handles various grades of manganese ore, which are brought in by rail transport and stockpiled up until a ship is ready to load it (GMC EMP, 2004). Annual shipment averages 1.5 million tonnes of material and the significant environmental aspect is also dust emission. Similarly, Takoradi Flour Mills Limited (TFL) produces 150,000 tonnes of flour annually from imported wheat and has flour, wheat dust and chaff as the significant environmental aspects (TFL EMP, 2004). Total Oil Marketing Company's Bitumen plant receives bulk bitumen from cargo ships via pipelines into enclosed tanks that are heated to keep it molten all the time (Total Bitumen EMP, 2004). On the average 14,000 tonnes of bitumen are delivered to various customers. Shell Oil Marketing Company's Bitumen Plant operates a similar facility and delivers three times the capacity of Total Bitumen plant. The significant environmental aspect relating to these two similar activities is mainly hydrocarbon vapours from the heating of the bitumen.

The location of the study area falls within the wet-equatorial climate zone of Ghana. The mean annual rainfall is 1350mm, ranging from 1200mm to 2200mm per annum. The area experiences two rainfall seasons from May to July and from September to November. Mean annual temperature is 26^{o}C. The relative humidity shows a diurnal variation around 95% overnight and falls to 70-80% during the day. The predominant winds over the harbour area are the South Westerlies and North Eastern Trade winds. The former is experienced over the area from February to October and the latter from November to January. Atmospheric stability is generally high and average wind speeds rarely exceed 4.5 knots. The predominant wind directions are Northeast. Occasionally, the wind direction is Southwest. However, depending on diurnal land/sea breeze effects, wind direction sometimes varies slightly each day throughout the year to the South, North, West and East. At times, daily wind direction variations are from East-North-East and West-South-West sectors.

Problem statement

The harbour industrial area of the twin city of Sekondi-Takoradi, as the centre of industrial activities is a major source of air pollution. The major pollutant is dust emissions resulting from the activities of the following industrial establishments: Ghacem, Takoradi Flour Mills, Ghana Bauxite Company and Ghana Manganese Company.

Dust monitoring exercises were conducted on behalf of Ghacem by SGS, and Environ Engineering and Management Consult (EEMC) both environmental consultancy firms from the period 1995 to 2004 for specific sampling locations. The exercise was conducted using two scenarios as follows: dust measurement during clinker discharge and dust measurement during no clinker discharge for both TSP and PM_{10}. The results obtained from the two scenarios for TSP indicated that with the exception of the Elf/Shell Bitumen plant where emission of TSP was higher, the other two monitoring locations (Takoradi Flour Mill and Ghacem Welfare Block) TSP values were relatively lower when compared with the EPA Guideline Limit of 230μg/m^3. On the other hand during clinker discharge the TSP values at the Elf/Shell Bitumen plant and Takoradi Flour Mill far exceeded the EPA Guideline Limit of 230μg/m^3 for TSP.

With regard to the PM_{10} level measurements, the results of the study suggest that with the exception of the Elf/Shell Bitumen plant, which recorded 63μg/m^3 during 'no clinker discharge', the Takoradi Flour Mill and Ghacem Welfare Block exceeded the EPA Guideline Limit of 70μg/m^3. Additionally, the values recorded during clinker discharge operation indicate that the PM_{10} values exceeded the EPA limit of 70μg/m^3 for all three locations (Appendices 1 & 2).

The two dust monitoring exercises were not conclusive in identifying the sources that contributed to the dust values obtained. Additionally, there has not also been any study to determine the effect of dust pollution on human health, structures and the environment with respect to the study area. The possible health consequences of the high dust pollution at the study area were ascertained from clinical historic data of the top five diseases compiled from 2004 to 2006 of three clinics that cater for staff working at the port industrial area. These clinics were the Ghacem clinic that caters for workers of Ghacem and their dependants, Twin City Clinic which caters for workers of Takoradi Flour Mill Limited and Ghana Ports and Harbour Authority Clinic which particularly services employees of the Port and the general public at large. From the data obtained from the clinics (Appendix 3), the related medical conditions that could possibly be linked to particulate dust pollution are the respiratory tract infection (RTI), skin diseases including ulcers and acute eye infection. Indeed, air pollution levels at the port industrial area is quite high and the associated medical conditions also exist according to the data gathered. In addition there has been an increasing consciousness and agitations of people living within the port industrial area about the high levels of particulate matter pollution and its health implications. Civil Society Organizations (CSOs), especially environmental pressure groups have also raised concerns on matters relating to the environment and the social well being of the people within the harbour environ.

Therefore the focus of this study is to determine the levels of air pollution and to propose mitigation measures that would help minimize or eliminate the dust pollutant from the environment so that workers, customers, visitors and neighbours alike would enjoy and breathe air which will most likely not aggravate an already worsened medical condition or influence ill health.

Objectives of the study

The general objective of the study is to investigate the particulate matter pollution levels in the Takoradi Harbour Industrial area.

The specific objectives of the study are to:

- Identify the air pollution sources within the Harbour industrial area;
- Determine the air pollution levels for both dry and wet seasons;
- Determine the concentration levels of TSP and PM_{10} at the different sampling locations (or targets) of the Harbour Industrial area;
- Determine whether or not there is any difference in dust measurements taken during the dry season and the wet season;
- Develop a practical and workable pollution control measures to effectively reduce particulate matter emissions from the Takoradi Harbour industrial zone; and
- Make recommendations towards effective reduction in particulate matter emissions from the Takoradi Harbour industrial zone.

Research questions

- What are the air pollution sources within the Harbour industrial area?
- What are the air pollution levels and trend of air pollution for both dry and wet seasons for each sampled location?
- What are the concentration levels of TSP and PM_{10} at the different sampled locations (or targets) of the Harbour Industrial area?
- Is there any difference in air pollution levels between the dry season and the wet season?

- What practical and workable pollution control measures can be developed to effectively reduce particulate matter emissions from the Takoradi Harbour Industrial area?
- What recommendations can be made towards effective reduction in particulate matter emissions within the Takoradi Harbour industrial area?

Significance of the study

Until now if dust monitoring campaign is to be staged in the Western region, equipment and staff required for this study will have to come from Accra, Tema or better still from outside the country. The study has therefore helped to build and establish local capacity for air quality monitoring.

The region can depend on the expertise of personnel in this region (specifically from Ghacem Limited) to conduct dust monitoring campaign in the future. This is because the company has acquired a set of dust monitoring instruments and is in the process of acquiring some more for internal monitoring and control purposes.

The acquisition of the dust monitoring instruments and the training of staff in monitoring and data collection clearly demonstrate the commitment of Ghacem management in dust reduction measures and to even extend this benefit to other companies for the realization of a city-wide data collection and evaluation processes.

The study has provided air quality data on the harbour industrial zone which will serve as baseline data to measure the benefits of planned investments and continuous improvement programs. The lack of air quality monitoring data for sub-Saharan African cities including Accra, Tema, and Takoradi makes it difficult to determine the severity of particulate matter pollution and to target problem areas by developing cost-effective solutions. The data compiled in this study can help build public awareness regarding air pollution and inform policy-makers of the need to include air quality management programs in their policy formulation strategies.

The study has provided vital information to management of industrial establishments about the levels of particulate emissions from their operations into the external environment, the workplace environment and their related effects on targets such as human beings and installations. This will thus inform the management of these establishments to take action before issues degenerate into serious environmental and social matters. As companies live up to their social responsibilities there will of course be social well-being which will come from judicious use of resources including the environment services. This undoubtedly will eliminate or reduce to the barest minimum public protests, outcry and conflicts which often heighten tension in industrial areas and at times lead to wanton destruction of properties.

The study also adds to existing literature of what EPA has done so far in the two cities and what the individual companies themselves have also done over the years.

Scope of the study

There are several industrial zones in the twin-city of Sekondi-Takoradi but the research study focused on the harbour industrial zone. Within this industrial area, activities that were monitored were the following:

- Cement manufacturing by Ghacem limited,
- Flour production by Takoradi Flour Mills Limited,
- Bauxite handling and loading by Bauxite Ghana limited,
- Manganese handling and loading by Ghana Manganese Company limited, and
- Total/Shell bitumen plants.

The study area was subdivided according to the nature of operation and by sampling points. The study monitored ambient air around these locations as was designated in the location map of the harbour industrial area. Samples were taken to determine the concentration of dust pollutant. The determination or analysis of the constituents of dust pollutants sampled was outside the scope of this study since the processes involved are complicated and not available locally.

Based on the monitoring results of the particulate matter, attempt was made to propose mitigation measures to minimize the effect of the emissions. In proposing control and management strategies, it would have been useful to collect data and information on existing control systems and management plans from industries within the study area, but this was not possible. Instead, a general control strategy which could easily be adopted and integrated into any management system was proposed. Although the study also recognized serious health implications associated with particulate matter pollution especially fine dust (PM_{10}) particles, it does not cover the effect of Particulate Matter Pollution on health.

Definition of terms

Pollution may be defined as the introduction by man into the environment of substances or energy liable to cause hazards to human health, harm to living resources and ecological systems, damage to structures or amenity, or interference with legitimate uses of the environment.

This definition is based on a more restricted one evolved by the Group of Experts on Scientific Aspects of Marine Pollution (GESAMP, 1972). It also closely follows the definition used in Article II of the Paris Convention on the Prevention of Marine Pollution from Land-Based Sources, and has something in common with the terminology used in documents of the United Nations Conference on the Human Environment (the Stockholm Conference) and the United Nations Environment Program (UNEP).

The important concepts in this definition are (Holdgate, 1979):

- Pollution is caused by substances or energy;
- It has a source or sources, and they are created by man. Natural inputs of the same substances are excluded. Thus pollution is an increment added by man to biogeochemical cycles;
- Pollution acts in the environment, as a result of these discharges, and follows a pathway, leading to the exposure of structures or organisms;

- The significance of the pollution is related to its effects on a range of targets (or receptors), including man and the resources and ecological systems on which he depends;
- Pollution is judged by its impact on social values as well as environmental components: if there is damage to structures or amenity, or interference with legitimate uses of the environment, the substances causing the effect are by definition, pollutants.
- Quantification of the scale of the hazard or damage or interference is important, and the basic question is one of acceptability of the consequences of the release of the substances or energy.

The location of the pollutant and its effects in space and time are crucial, that the quantity of pollutant and scale of effect must be evaluated, and that a value judgment about what is acceptable (or 'wrong') is inevitable. Pollution has to be seen in a socio-economic context. That is why there is so much argument about it.

Standards pertain to environmental requirements of the country or the local authority, while Guidelines are suggested practices by organizations such as The World Health Organization and The World Bank.

Standards are statements about the levels of target exposure or pollutant concentration that are considered acceptable at particular times and under particular circumstances. As SCOPE (1977) points out, there are two main types:

- Those specifying maximum permissible levels of environmental contaminants (or target exposures or doses);

- Those specifying minimum permissible qualities of performance of a human product (e.g. factory ventilation or dust arrestment: this kind of standard is applied to many types of building, like dams and bridges, outside the pollution field).

Standards are formulated as part of regulatory operations and have at least some basis in law.

Goals or objectives just as standards also specify desirable maximal target exposures or pollutant concentrations, but goals and objectives are not normally backed by law. An Ambient Air Monitoring Program is defined as a network of monitoring stations that measure air pollutant concentrations that can be compared to national and international standards and guidelines. Adverse effect is defined as "any effect resulting in functional impairment and/or pathological lesion that may affect the performance of the whole organism or which contributed to a reduced ability to respond to an additional challenge".

CHAPTER TWO

REVIEW OF LITERATURE

Air quality monitoring in Ghana

Not so much study in air quality has been done in Ghana. The lack of air quality monitoring data in sub-Saharan African cities has given cause to the setting up of the air quality monitoring project which is still on-going in Accra. The project comprises the following elements: the first phase of monitoring which was to be conducted for seven months to establish initial baseline data for key pollutants and to develop local capacity needed to sustain and build on the project in the long term.

Trainees were to be provided with hands-on air quality monitoring training and mentoring. Policy-makers were soon to be provided with data outlining the general scope of the air pollution. Recommendations from the first phase of monitoring were to be expanded to develop a broader air quality management program for the city of Accra.

During a discussion with the Western Regional Officer of Ghana EPA, it was mentioned that air quality monitoring data had been collected in Tema and New Takoradi, a suburb of Takoradi, but the data had not yet been analyzed to use it to formulate mitigation or control strategies.

The Ghana EPA has been collaborating with United Nations Industrial Development Organization (UNIDO) to undertake cleaner production demonstration projects in industries since 2000 (UNIDO CP Seed Fund Project, 2005). The projects have been sponsored by the Government of Norway.

The concept of Cleaner Production applies continuous integrated preventive environmental strategy to processes, products and services to enhance efficiency through techniques such as:

- Technological change,
- Change in input (or raw) material,
- Good housekeeping,
- Product change,
- On-site reuse or recycling,
- Process optimization,
- Equipment modification, and
- Training and work instruction.

The enhanced efficiency undoubtedly leads to improved environmental performance, cost savings and reduction of risks to humans and the environment. For production activities, cleaner production (CP) includes conserving raw materials and energy, eliminating toxic materials and reducing the quantity and toxicity of all emissions and waste before they leave the process.

The demonstration projects have focused on the applicability of CP in Ghanaian industry, while building national capacity in CP assessment at the enterprise level. UNIDO is continuing its efforts to mainstream CP strategy in environmental management system development in Ghanaian industries and to facilitate support and funding for the establishment of National Cleaner Production Centre (NCPC) in Ghana.

In line with this objective, UNIDO supported a Seed Fund Project Phase II for in-plant CP assessment capacity building in EPA permitted indiustries. This brought the total industries that have benefitted from the UNIDO CP funded programmes to 30 by the end of 2005.

The National Cleaner Production Centre (NCPC) that is being set up in the country will enable Ghana actively involve in a Regional Network of CP Centres of Excellence that is emerging under the Africa Roundtable on Sustainable Consumption and Production (ARSCP), which is duly recognized by African Ministers Conference on Environment (AMCEN).

CP is a tool for managing environmental projects in a company to reduce environmental impact and to increase profit. It is a continual process to ensure an environmentally sound and sustainable development in a company and is a proactive approach to waste management. Fairly new in Ghana, CP is being demonstrated on a pilot basis and will still take sometime before Ghanaian industries embrace its concept and adopt it.

Air quality models and control strategies

The Decision Support System for Integrated Pollution Control (DSS) has been developed by the World Bank, in collaboration with World Health Organization and Pan American Health Organization, to allow a rapid assessment of the pollution situation in a specific geographic location, such as a metropolitan area or water basin, and to assist in the analysis of alternative pollution control strategies and policy options (Guven, 2001). The DSS is a personal computer software program and database that has been developed from the approach and parameters provided in the 1989 WHO working document on Management and Control of the Environment. This approach generates estimated pollution loads in a study area by applying emission factors to data on economic activities. This load data can then be further processed to estimate area-wide concentrations or to examine the impacts and costs of selected pollution control measures. (Full details of the system, the basic assumptions and the base parameters are given in the manual that accompanies the software.)

The databases compiled by medium of discharge include:

- Pollution-intensive technological processes across all sectors of economic activity, including mining, manufacturing industries, energy, transport and municipal sectors, grouped according to the UN International Standard Industrial Classification (ISIC) at 4-digit level. The list outlines the different process options and unit processes employed in a given industrial activity. This could be used in the initial phases of the inventory work as a checklist to identify the existing major industrial operations in the study area;
- Principal control options available for each process, including good housekeeping and waste prevention programs;

- Emission factors associated with these processes and process-control option combinations;
- Normalized costs and parameters for control technologies; and
- Health guidelines for air and water pollutants where applicable.
- Editing and calibration features of the software allow adjustments of the default data to local conditions, when actual information is available.

Advantages of the DSS for integrated pollution control

As an analytical tool, the DSS can be used as the first step in analyzing pollution control policies, such as setting environmental standards or applying economic instruments, by:

- estimating costs of attaining proposed emission and/or ambient standards in an area
- estimating the impact on ambient quality of proposed emission and technological standards
- allocating emission limits across pollution sources in an area in a cost effective way

As an educational tool, DSS helps to make transparent key issues and causal links in pollution management. It can demonstrate the comparative effect on pollution load and ambient quality of a number of factors that can be affected by sectoral and environmental policies. It can promote public participation and consensus building by informing various stakeholders about the key pollution problems, major pollution sources and principal mitigation measures in the area.

Its main advantage is in helping to create a comprehensive picture of the pollution problems in a more quicker way of an area so that further analysis on specific priorities can be pursued.

Limitations of DSS

Although the DSS database can provide information on pollutants, emissions factors, technological processes, control options, and unit costs that can be independently applied in other models or studies, or serve as a point of reference, the range and variability of the parameters included is frequently too large to give reliable results. The database has to be validated or adjusted for local conditions whenever possible and may therefore give information that may not represent the true picture on the ground.

It may be useful for a one-off quick assessment and evaluation of an environmental condition pertaining to a particular study area so appropriate decisions can be taken but the system cannot be relied upon for continuous monitoring of an environmental condition. This will require the use of specialized instruments.

Environmental management through Systems Approach

The systems approach (Economopoulos, 1987) have so been designed to offer cost effective alternative as well as systems that are manageable and can be enforced through the industries desiring to control particulate dust emissions or any pollutant into the atmosphere. These objectives can be achieved by formulating detailed action programs through system analysis.

The term detailed action program include specific technical or institutional measures, legislative instruments, emission standards, social interactions with neighbours, corporate image, environmental consciousness, pollutant monitoring and planning teams.

The monitoring team is entrusted to identify the major pollution problems in an industrial setup and to develop a detailed control program. This is to be achieved through a systems analysis scheme as shown in Figure 1.

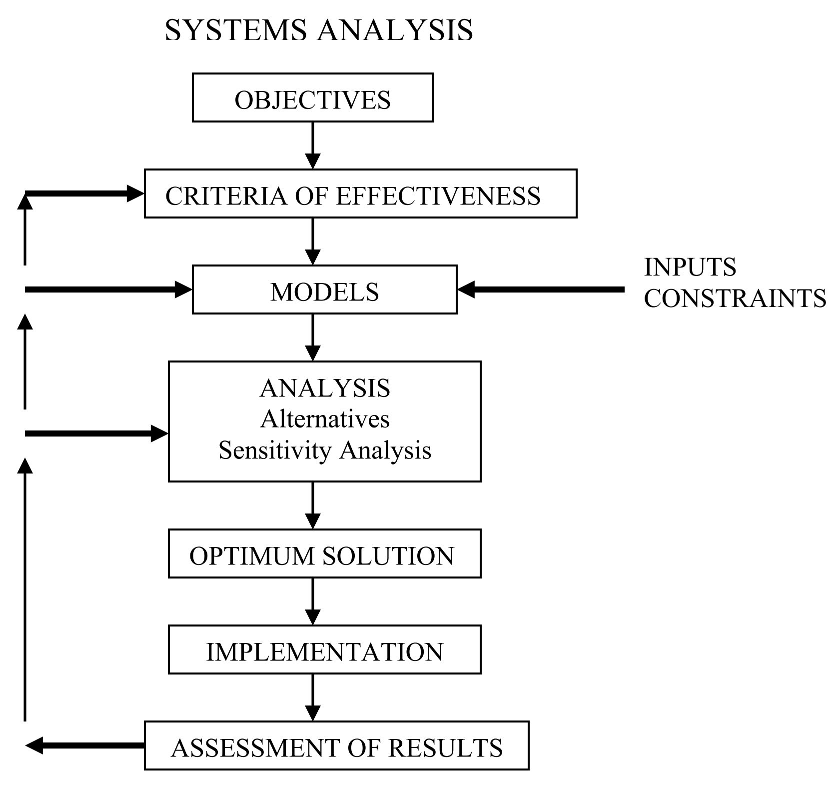

Figure 1: Systems analysis scheme

Source: Economopoulos, 1987

The first major task in the systems analysis procedure is definition of the strategy objectives. In the case of particulate dust emission, the general objective is to safeguard human health, and the environment in general (e.g. maintain an acceptable air quality consistent with either WHO or EPA Guidelines).The prime objective of most environment management studies is the observance of these standards.

The second major task is the definition of the criteria of effectiveness, which has to be compatible with the objectives, so as to enable the user to know when the objectives are fulfilled or how effective a particular set of measures is towards meeting the objectives. The criteria of effectiveness are normally the pollutant concentrations in the ambient air.

The application of an appropriate air quality model is the third major task and this allows users to identify the nature and severity of existing pollution problems and to test the effectiveness of alternative control measures. Naturally, the end output from the application should be compatible with the study objectives that have been set and with the accepted criteria of effectiveness. Testing of control options and analysis of sensitivities is the fourth major task and consists of the systematic screening of all available control options and evaluation of their relative effectiveness from the environmental, cost and enforceability point of view. The end product of this exercise can be a table listing the effectiveness of selected measures against the set objectives and possibly the assignment of priorities to such measures.

The formulation of optimum strategies is the fifth major task in the systems analysis procedure and comprises the selection of a set of enforceable measures, through which all the set objectives are met with the least cost. Figure 2 provides a more advanced scheme for the formulation of pollution management strategies. In this, source inventory techniques are employed to provide input into the appropriate air quality model, and monitoring data are used for the calibration and fine-tuning of the latter. This model can be applied to provide a clearer picture of the current quality of the environment and to detect possible excesses above the accepted set of quality criteria or standards.

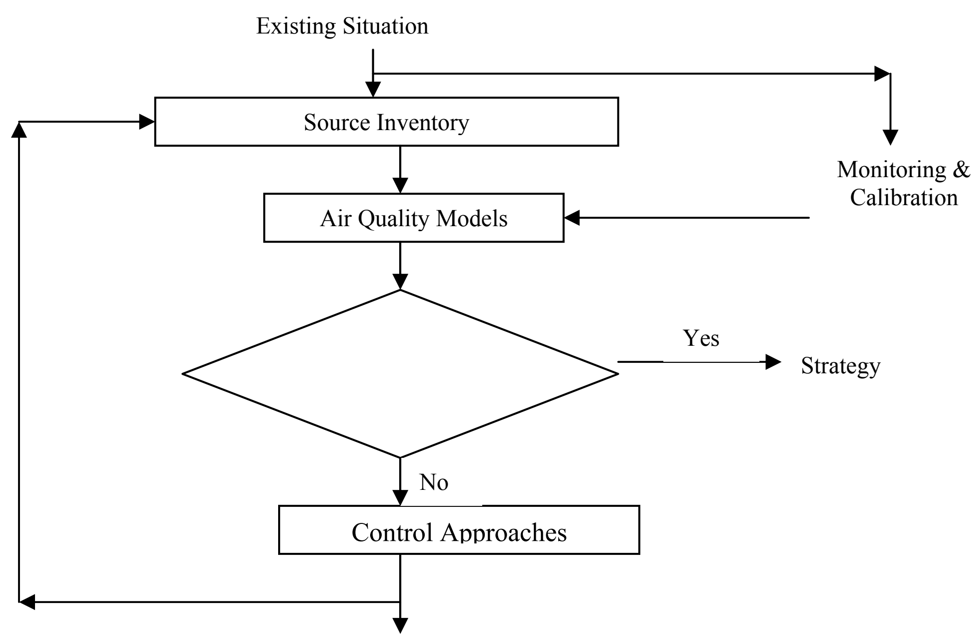

Figure 2: Feed-forward approach for strategy formulation

Source: Economopoulos, 1987

If excesses are detected, control approaches can be drawn up and their effectiveness in improving the situation can be conveniently tested through the already calibrated air quality models. Control approaches drawn and tested this way can be modified as many times as necessary until a suitable one is found that meets the set environmental, cost and organizational requirements and constraints in the most rational manner.

The sixth major task in the systems analysis procedure is the implementation of the formulated strategy. As a general rule, measures selected through the strategy need further analysis and verification prior to implementation. The statistical validity of the assessments should always be kept in mind through the use of waste load factors as should significant deviations from predictions for single sources.

Assessment of the end results concludes the major tasks in the systems analysis procedure and this includes the possible adjustment of the initial strategy and it should be borne in mind that the process of making assessments of environmental pollution is not a single effort but rather an on going process, which builds up from the feedback of past experiences and results.

Air quality model

The air quality model allows the assessment of the released loads under selected control measures. The quantities of emissions released into the atmosphere (Economopoulos, 1993) from any industrial or other activity depend, in general, on a number of parameters. Thus, the emission E of pollutant j could be expressed in a mathematical form as follows:

Ej = f (source type, unit of activity, source size, process or design particularities, source age and technological sophistication, source maintenance and operating practices, type and quality of the raw materials used, type, design and age of the control systems employed, ambient conditions, etc)…………………………………..........................Equation 1

The source type defines the kind of pollution generating activity in somewhat broad terms, e.g. cement manufacturing, vehicle traffic, external fuel combustion. Obviously, the source type is a parameter which is closely related to the type and quantity of pollutants emitted.

Through the source type parameter alone it is possible to simplify very substantially the source inventory and the air pollution management tasks by excluding right from the start numerous activities with relatively minor air pollution potential.

The unit of activity, referred to simply as unit hereafter, defines an acceptable way of expressing the activity of a given source. Suitably defined units can be used to provide a measure of the products manufactured (e.g. the quantity of cement produced by a cement manufacturing plant).

Source size, although a key parameter, is only indirectly related to the normalized emissions rate (emission loads per unit activity). In general, economies of scale allow better design and operation, as well as stricter emission controls for larger size units. Moreover, for industrial sources, selection of the particular process to be used is often dictated by plant size. It is for these reasons that emission standards are generally significantly stricter for large plants.

Process or design particularities are very much related to the kinds and to the quantities of pollutants emitted from industrial sources. For example, different kinds of kilns in the production of lime and cement, or different types of furnaces in the metallurgical industry result in greatly varying emission rates.

Source age and technological sophistication are important parameters, as they often significantly affect the emission loads. The aging of a source causes higher emissions as systems tend to fail more frequently and their operation tends to depart from the new equipment specifications. In addition, older systems do not take full advantage of technological innovations, which tend to yield environmentally friendlier performance. Naturally, the technological sophistication does not only depend on the age of the source alone, but also on the environmental legislation, as well as on enforcement aspects.

Source maintenance and operating practices is another parameter significantly affecting emission loads. Fortunately, for the vast majority of industria1 sources, proper maintenance and operation is also intimately related to product quality and costs and for this reason is usually practiced to acceptable standards.

The type and the quality of the raw materials used are in many cases inti-mate1y related to the types and to the quantities of pollutants emitted. In industrial processes the type and the quality of raw materials available often dictate the process to be used and the emission loads released by them. The type, design, and age of the control systems employed determine the removal efficiencies of the source emissions and are thus intimately related to the loads eventually released into the atmosphere.

The type of the control system employed defines by itself the capabilities and limitations (and hence the control efficiency range) for the source under consideration. Analytical design characteristics allow a better insight and a more accurate assessment of the control system efficiency, but relevant data are difficult to collect in practice and difficult to use. The age of the control system affects the emissions due to the progressive downgrading of the performance with time, but, most importantly, due to the generally more relaxed design specifications of the past.

The ambient conditions may significantly affect the rate of emissions. For example, wind velocity and/or rainfall affect the TSP emissions from roads and material storage facilities, while temperature affects considerably the road traffic emissions. The impact of the ambient conditions has been incorporated in the emissions model for selected sources.

The above discussion leads into the important practical question of how the emission load Ej could be expressed as a direct and explicit function of all the parameters that may affect it for all pollutants j of interest. The first step in this direction is to define the emission factor ej for pollutant j, through the following relation:

ej = Ej, (kg/yr) / Source activity, (Units/yr) ……………………………Equation 2

The emission factor ej is normally expressed as kg/unit and is assumed to be independent of the source size and the source activity (or production) level.

The basis for this important assumption is the way the activity units are selected. Indeed, as discussed above, a key criterion in the selection of the activity units is their direct and proportional relation to the emission loads generated. From the above and from Equation 1 we obtain:

e j = f' (source type, process or design particularities, source age and technological sophistication, source maintenance and operating practices, type and quality of the raw materials used, type, design and age of the control systems employed, ambient conditions, etc)……………………..………………………..Equation 3

The emission factor ej is used extensively hereafter, as the key objective of the air emissions model to define the value of ej for every significant source and for every pollutant of interest j. The dependence of the emission factors ej on the parameters discussed above and listed in Equation 3, cannot, in most cases, be expressed in a continuous function form due to the discreet nature of most parameters (e.g. type of fuel or type of control equipment used), and to the frequent lack of sufficient information in relation to the remaining parameters. A discreet functional form yielding a series of emission values, each valid under a specific set of common and important parameter combinations, is used instead.

The discreet rather than the continuous nature of the emission factor values leads into a tabular construct of the model, into which the source types are organized on the basis of the UN Standard Classification of Industries and Services. Under each activity listed, all important individual sources are included (e.g. under Cement manufacturing, the Tube Mill/Open Cycle and the Tube Mill/Closed Cycle or Roller Mill options are included); for each such source all major alternative processes are listed (e.g. in Cement manufacturing and under Tube Mill/Open Cycle, the Uncontrolled, the Fabric Filter and the Electrostatic Precipitator control alternatives are listed). Similarly, for Cement manufacturing and under Tube Mill/Closed Circuit, the Uncontrolled, the Fabric Filter and the Electrostatic Precipitator control alternatives are also provided). For each such combination of parameters the applicable emission factors are given for the pollutants of interest.

The model is a valuable tool for source inventory studies, not only for computing the emissions, but also for providing guidance on the data to be collected during the field survey work, as well as for organizing and presenting such data in a concise manner. In addition, the model is a valuable tool in air pollution management studies as it provides a clear picture of the existing sources and emissions and, along with it, a fairly comprehensive list of the available alternative process modifications and control equipment options for each activity and each source therein, as well as identification of the parameters that exert a particular influence on the emissions and quantification of relevant changes (e.g. quantification of the impacts from possible changes in the types and qualities of the fuel used). The above constitute key elements in the analysis of air pollution problems and the formulation of effective control strategies for any given urban or industrial area.

Finally, the model is useful in Environmental Impact Assessment Studies as it provides, in a convenient form, quantification of the impacts of alternative process and emission control system selections for most sources and activities of interest.

Approaches to pollution prevention

In general, pollution prevention approaches include management measures, choice of fuel and choice of technology and processes. Measures such as improved process design, operation, maintenance, housekeeping, waste management and other management practices can reduce emissions. By improving the combustion efficiency, the amount of products of incomplete combustion (PICs), which is a component of particulate matter, can be significantly reduced.

Atmospheric particulate emissions can be reduced by choosing cleaner fuels. The use of natural gas as fuel emits negligible amounts of particulate matter. Low-ash fossil fuels contain less non-combustible, ash-forming mineral matter and thus generate lower levels of particulate emissions. Lighter distillate oil-based combustion results in lower levels of particulate emissions than heavier residual oils. However, the choice of fuel is usually influenced by economic and environmental considerations. The use of more efficient technologies or process changes can reduce particulate matter and other gaseous emissions whilst at the same time improving the efficiencies of the processes.

Approaches to emission control

A variety of particulate removal technologies are available with different physical and economic characteristics:

- Inertial or impingement separators rely on the inertial properties of the particles to separate them from the carrier gas stream. Inertial separators are primarily used for the collection of medium-sized and coarse particles. They include settling chambers and centrifugal cyclones (straight-through, or the more frequently used reverse-flow cyclones).
- Electrostatic precipitators (ESPs) remove particles by using an electrostatic field to attract the particles onto the electrodes.
- Filters and dust collectors (baghouses) collect dust by passing flue gases through a fabric which acts as a filter. The most commonly used is the bag filter or baghouse. The various types of filter media include woven fabric, needled felt, plastic, ceramic and metal (Croom, 1993).
- Wet scrubbers rely on a liquid spray to remove dust particles from a gas stream. They are primarily used to remove gaseous emissions, with particulate control as a secondary function. The major types are venturi scrubbers, jet (fume) scrubbers, and spray towers or chambers.

Table 2 lists advantages and disadvantages of particulate removal control technologies.

Equipment selection

The selection of PM emissions control equipment is influenced by environmental, economic and engineering factors.

Environmental factors include:

- the impact of control technology on ambient air quality
- the contribution of the pollution control system to the volume and characteristics of wastewater and solid waste generation
- maximum allowable emissions requirements.

Economic factors include:

- the capital cost of the control technology.
- operating and maintenance costs of the technology.
- expected lifetime and salvage value of the equipment.

Engineering factors include:

- contaminant characteristics such as physical and chemical properties – concentration, particulate shape, size distribution, chemical reactivity, corrosivity, abrasiveness, and toxicity.
- gas stream characteristics such as volume flow rate, dust loading, temperature, pressure, humidity, composition, viscosity, density, reactivity, combustibility, corrosivity, and toxicity.
- design and performance characteristics of the control system such as pressure drop, reliability, dependability, compliance with utility and maintenance requirements, and temperature limitations, as well as size,

weight, and fractional efficiency curves for particulates, and mass transfer and/or contaminant destruction capability for gases or vapours.

Table 2: Advantages and disadvantages of particulate control technologies

Advantages	Disadvantages
Inertial or impingement (Cyclone) Separators	
Low capital cost; Relative simplicity and few maintenance problems; Relatively low operating pressure drop; Dry collection and disposal; and Relatively small space requirements.	Relatively low overall particulate collection efficiencies, especially for particulars sizes below 10 um; and inability to handle sticky materials.
Wet scrubbers	
No secondary dust sources; Relatively small space requirement; Ability to collect gases, as well as particulates (especially 'sticky' ones); Ability to handle high-temperature, high-humidity gas streams; Low capital cost (if wastewater treatment system is not required); High collection efficiency of fine particulates.	Potential water disposal disposal/effluent treatment problem; Corrosion problems; Potentially objectionable steam plume opacity and/or droplet entrainment; Potentially high pressure drop; Potential problem of solid buildup at the wet-dry interface; relatively high maintenance costs.

Table 2: Advantages and disadvantages of particulate control technologies (Continued)

Advantages	Disadvantages
Electrostatic precipitators	
Collection efficiencies of 99.9% or greater for coarse and fine particulate at relatively low energy consumption;	High capital cost;
Dry collection and disposal of dust;	High sensitivity to fluctuations in gas stream conditions;
Low pressure drop;	Difficulties with the collection of particles with extremely high or low resistivity;
Continuous operation with minimum maintenance;	Relatively large space requirement for installation;
Relatively low operation costs;	Explosion hazard when dealing with combustible gases or particulates;
Operation capability at high temperatures and high pressures;	Associated with very high voltage;
Capability to handle relatively large gas flow rates (the order of 50,000m^3/min).	Production of ozone by the negative charged electrodes during gas ionization; and
	Highly trained maintenance personnel requirement.

Table 2: Advantages and disadvantages of particulate control technologies (Continued)

Fabric filter systems (Baghouses)	
Advantages	Disadvantages
Very high collection efficiency (99.9%) for both coarse and fine particulates; Relative insensitivity to gas stream fluctuations; Filter outlet air can be re-circulated; Dry recovery of collected material for subsequent processing and disposal; no corrosion problems; Simple maintenance, flammable dust collection in the absence of high voltage; High collection efficiency of submicron smoke and gaseous contaminants; Various configurations and dimensions of filter collectors; and Relatively simple operation.	Requirement of costly refactory mineral or metallic fabric at temperatures in excess of 290^{o}C; Need for fabric treatment to remove collected dust and reduce dust seepage of certain dusts; Relatively high maintenance requirements; Potential explosion and fire hazard of certain dusts; Shortened fabric life at elevated temperatures; Potential crusty caking plugging of the fabric, or need for special additives due to hygroscopic materials, moisture condensation, or tarry adhesive components.

Source: Adapted from Bounicore and Davis, 1992

Control and management options

There are a number of control options for managing environmental impacts. For corporate organizations, these options can be categorized into the following:

- Public pressure feedback for environmental action
- Best practical control technology principle
- Environmental management systems, and
- Environmental management systems standards.

Environmental problems are bound at some stage to cause public concern and increased pressures for improved controls. In response to such pressures the pollution inspectorates tighten the measures until the situation is brought back to normal. This mechanism is apparently cost effective, as measures are taken only up to the degree required. However, the response is slow, as it takes time for results to appear, and the entire mechanism is better suited to address pollution problems of local rather than global significance. For example, urban pollution is likely to be a far more sensitive issue than trans-boundary or global air pollution for urban residents. As far as developing countries are concerned, implementation of similar approaches is difficult since a key prerequisite for their success is the existence of a highly competent inspectorate infrastructure, as well as safeguards for the unbiased and smooth operation of the entire system.

Strategies based on the best practical control technology principle clearly entail the highest costs, as the best practical control techniques are always implemented, even when this is not directly justified by the local pollution problems. They provide the possibility of swift action, as relevant control programs are drafted by central planners and become automatically effective over an entire region or country. Moreover, trans-boundary and global pollution problems are best served by these environmentally responsible practices.

Approaches of this type, where highly competent central planners define the action programs, are among the easiest to implement, and as such they are suitable, in this respect, for developing countries. The high cost however, of the resultant environment programs may not represent the best allocation of the often limited resources in the developing world.

Environmental management systems can vary from simple broad-brush exercises to sophisticated systems, with thorough reviews of impacts, detailed documentation of procedures and environmental problems, and regular auditing of the system's operation. Formalization is required to achieve accreditation to the International Standard 14001 (ISO 14001, which has already or will in the future subsume most national standards such as British Standard BS7750) and the European Union Eco-Management and Audit Scheme (EMAS). In practice, all environmental management systems share five main elements:

- Identifying company impacts on the environment
- Understanding current and future legal obligations
- Developing plans for improvement
- Assigning responsibility for implementation of plans
- Periodic monitoring of performance

There are now two international standards for environmental management systems (EMS) - those of the International Standards Organization (ISO) and that of the European Union, which is the Eco-Management and Audit Scheme (EMAS). These build on the earlier experience of national EMS standards, notably British Standard 7750 (BS7750), which are now being withdrawn and replaced by ISO 14001. They are also inspired by the ideas of total quality management and the international standards on quality management systems (the ISO 9000 series).

A number of ISO standards and guidelines (collectively known as the ISO 14000 series) deal with EMS and related topics such as auditing and performance evaluation. The most important is ISO 14001, which sets out the criteria for accrediting the EMS itself. It focuses on the existence and adequacy of the key processes (as shown in figure 3) and whether these are thoroughly documented. ISO certification can be gained in any country and, in principle, can be obtained for any organizational level-site, division, or the entire organization. This is a key difference with EMAS, which is only applicable to sites within the European Union (and at present only those engaged in industrial activities, although it may be extended).

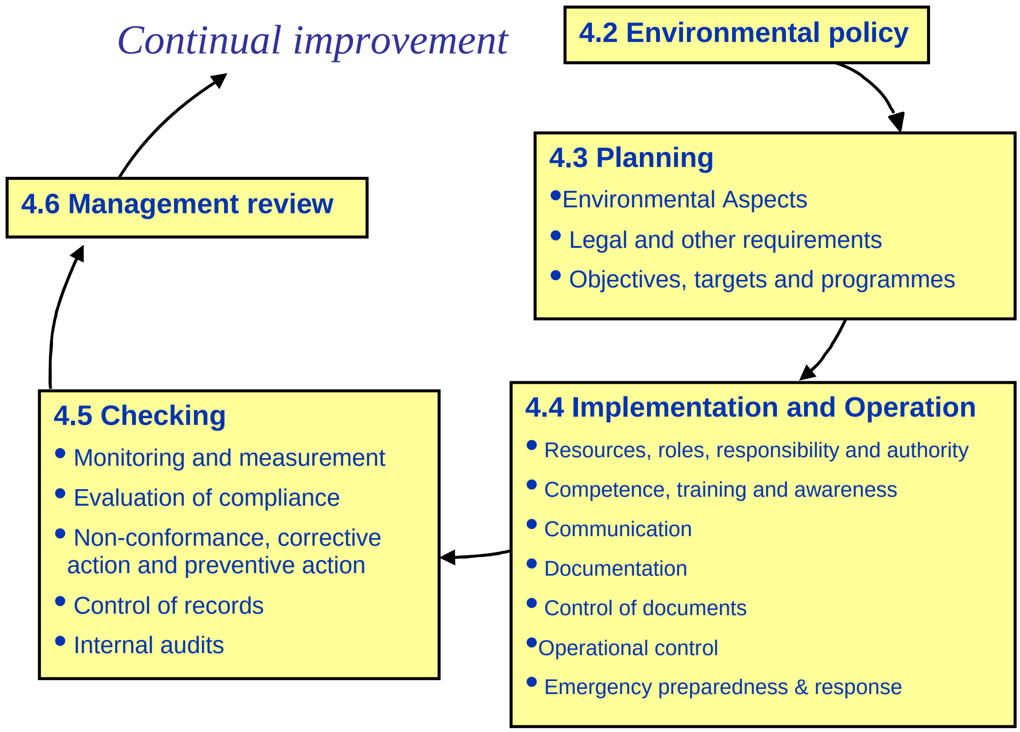

Figure 3: ISO 14001: 2004

Source: ISO 14001: 2004 Standard, 2004

Discussions of issues raised in the literature review

Any one of the concepts outlined in the Literature Review could have been used in this study because they only entail the collection of data to fit into a model after which decisions are made based on the outcome of the evaluation. Making assessments of environmental pollution and devising control and management strategies should not be viewed as a one-of effort, but rather as an on-going process. After an inventory of pollution loads has been made in a given area, it will need to be kept up-to-date and its accuracy improved. Similarly, control and management strategies will need to be reviewed as to their effectiveness and cost, while the efficiency of the implemented measures will need to be monitored and compared with predictions, so as to provide guidance for the future.

The rigorous approaches to environmental management are however a demanding undertaking as they involve, in general, detailed source inventories, series of sectoral techno-economic studies analyzing the available control options for all major pollution contributors, application of environmental quality models, sensitivity analysis and formulation of control and management programs in relation to the goals set. The above requirements, despite the potential benefits, render the implementation of these rigorous approaches prohibitive in most practical situations.

For most developing nations such as Ghana, where environmental problems are often critical and available resources scarce, environmental management approaches based on the best available control technology tend to be too expensive, while those relying on the imposition of selective controls through local inspectorate decisions and public opinion feedback, tend to be unworkable due to lack of inspector skills and other infrastructure requirements and long response times.

Most developed countries having faced acute pollution problems much earlier than the rest of the world, some of them since the dawn of the industrial revolution, have had ample time and resources to develop effective pollution control approaches. The control approaches used by the developed countries vary, often significantly, from country to country as they are affected by the multitude of factors such as:

- Nature of the pollution problems,
- The natural adherence to techniques used in the past,
- The enforcement and inspection infrastructure,
- The legal environment
- The priority of environmental issues in management and political thinking,
- The sensitivity of the people, and
- The availability of resources for the protection of the environment.

Some critics feel that the requirements of EMS standards create a bureaucratic, rule-based, approach to environmental management and that it is possible to meet them without major improvements in environmental performance. These dangers are real, not least for companies with long-established environmental, health, and safety systems.

Introducing these elements can be costly. Some companies with long experience of environmental management have found that incorporating environment into existing high-performance work systems can avoid these costs and still achieve equivalent performance.

However, an increasing number of organizations are finding environmental management systems to be useful and a valuable means of fostering eco-efficiency. The benefits include:

- Identification and control of business risks
- Identification of environmental and business improvement opportunities
- Early warnings of future environmental problems and costs
- More effective implementation of environmental policies

- Greater environmental awareness among staff

Accreditation of an environmental management system can bring the additional benefits of enhanced reputation with customers, regulators, and other stakeholders.

Conceptual framework

Total Quality Management (TQM) is a method of business management designed to improve the effectiveness, flexibility and competitiveness of any given organization, from the top to the bottom. It must embrace the whole organization: it involves each department, each activity, and each person, at every level. It extends far beyond the production process or customer service, because in order that a company may be truly effective, all its constituent parts must work in harmony, since each person and each activity affects and is affected by others. TQM is a complete and continuous process, hence the image of a circle of constant feedback and improvement, not the straight line of conventional business process analysis. It is a method of management which applies equally to both the service industries and to the manufacturing and processing sector.

The objective of TQM is to satisfy customer requirements as efficiently and profitably as possible. The basic philosophy has been described as "doing the right things right, first time, every time", (Munro-Faure "Implementing Total Quality Management"). TQM has become the term to be applied to any form of customer-focused corporate culture which concentrates on continual improvement, but there are certain fundamental ingredients which are necessary for its successful application. TQM begins by identifying first of all a company's customers, in the broadest sense of the word, one of whom should be the environment. Consideration for the environment can be built into a total quality program in exactly the same way as consideration for the people who pay the bills.

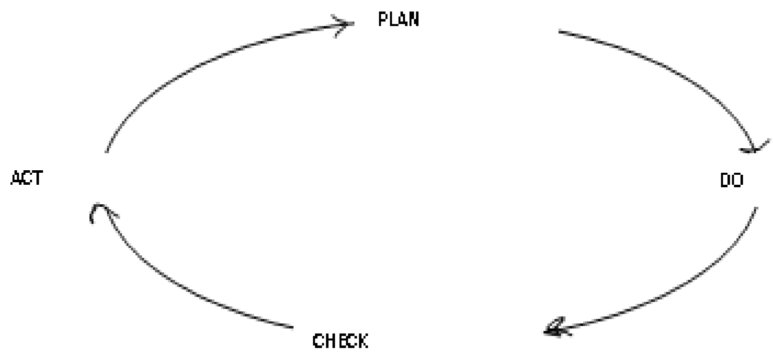

Figure 4: The Deming Cycle

Source: Operations management: Continuous improvement, 1994

Identifying an organization's customers, the requirements of those customers, and how those requirements will be met, form the core of the total quality approach. To succeed in this approach a company will need in place certain key elements: a good quality management system, environmental management system, statistical process control (SPC), and teamwork. TQM rests on a simple cycle of "plan → do → check → act" (Figure 4).

"Plan" involves the identification of external and internal customers, and stakeholders, the identification of point sources of emission and ambient conditions, identifying opportunities for improvement, defining objectives and setting targets, establishing EPA standards for TSP and PM_{10}, and the development of environmental management programs to achieve them.

One dimension of planning is developing an environmental quality infrastructure within the company. This should diffuse responsibility to, and synthesize the insights of everyone in the organization. One means of doing this is through the creation of quality teams that bring together representatives from all the functions – and any outside parties – involved in a particular environmental problem. Training to develop both environmental awareness and problem–solving skills is also vital. Identifying improvement opportunities is also a vital part of planning. Insights can come from cross-functional discussions, mapping energy and material flows, and interaction with customers and stakeholders.

The "Do" stage entails implementation and operation of the actions taken in the planning stage. This involves:

- assigning responsibility throughout the organization
- training, awareness and competence development
- dissemination of information

EMS documentation can be limited to the company's Environmental Management Plan (EMP) submitted to EPA, Operational Control and Emergency Preparedness and Response.

For the do stage, quality practice is to implement on a pilot or experimental basis to maximize learning. Many organizations that have introduced environmental management systems did so by implementing them at just one site before extending them to the remainder of the organization. Full implementation then requires assignment of responsibility for action and establishment of performance measures. The EMS will include preventive action, rectification at source and integration of environmental considerations into processes and routines.

“Checking” can occur in a variety of ways of varying formality, ranging from formal audits to informal team discussion. What is important is that performance is monitored and analyzed and that there are feedback mechanisms in place so that necessary changes can be made. It is also important that successes are recognized by awards, publicity, or other means.

The fourth, “Act” stage can integrate the whole cycle and prepare the ground for further improvement. The importance of meeting standards must be communicated and peer group pressure from good performers must be encouraged. The standards must also be re-calibrated to reflect continuing improvements in performance. Training and other support must also be provided. The cycle continues until the company achieves its target of 100% compliance. It is also important that culture is shared among neighbouring companies.

The application of some of the tenets of Total Quality Management (TQM) is considered more appropriate in this study than any other concept. This is because the study is dealing with heavy industries which by law are expected to meet certain legislative regulations, demonstrate environmental consciousness in their operations and ensure the sustenance of social interactions with neighbours for the maintenance of good corporate image.

The pursuit of quality is, of course, largely driven by commercial considerations, but there is an additional moral imperative associated with attaining a high level of environmental performance, and securing the health and safety of employees and members of the public. Many of the features of effective environmental management are indistinguishable from the sound management practices advocated by proponents of TQM.

The research will therefore use the total quality framework and quality tools and techniques in addressing the environmental processes. Because the environmental area is so important to top management of companies and other stakeholders, there is the need to ensure the continual incorporation of quality thinking into our environmental activities. It is therefore important for companies especially leading-edge businesses to develop and share knowledge about quality approaches to environmental management.

Hypothesis tested

Based on the review, conceptual framework adopted and the objectives of the study, the following hypothesis was tested:

Null Hypothesis (H_o)

There is no significant difference between the mean TSP or PM_{10} values for the harbour industrial zone and their corresponding guideline limits set by the EPA for both dry and wet seasons.

Alternative Hypothesis (H_1)

There is a significant difference between the mean TSP or PM_{10} values for the harbour industrial zone and their corresponding guideline limits set by the EPA for both dry and wet seasons.

CHAPTER THREE

METHODOLOGY

Sampling and data collection

Samples of ambient particulates were collected from designated points within the study area. Two pumps were in operation during each monitoring exercise. One set up (Pump 1) was used to monitor the TSP while the second setup (Pump 2) also monitored PM_{10}.

Location of sites for sampling was determined by concentrations of PM emissions from these sites. Areas known to have high concentrations of PM emissions could easily be identified within the study area and that formed the basis for selecting sampling sites. In addition the data compiled by Ghacem over the years on some selected monitoring sites (Appendices 1 & 2) also helped in the selection of sites.

With the help of the location map, and previous experience of PM concentrations in certain areas of the industrial zone (e.g. as indicated in Appendices 1 & 2), the sampling sites shown in Table 3 were identified together with their sampling frequencies.

Table 3: Sampling sites and frequencies

Location No.	Site Description	Sampling Frequency TSP	PM_{10}
1	1st Junction Tower	4	4
2	Fisheries/Trucks waiting point	4	4
3	Packing area (overlooking GAPOHA workshop	4	4
4	Between packing loading point and Flour Mill	4	4
5	Ghacem Welfare Block	4	4
6	Road in front of Ghacem gate	4	4
7	Total/Shell Bitumen plants	4	4
8	GAPOHA Market	4	4
9	Flour Mill Entrance	4	4
10	Manganese unloading point	4	4
11	Back of TFM offices	4	4
Total number of samples		44	44

Source: Field survey, 2007

In addition to the air monitoring data, climatological data of the study area was also compiled from July 2006 to January 2007. The climatological data consisted of the rainfall (mm), temperature max/min, wind direction, wind speed, and relative humidity of the study area, Appendix 4.

Generally, the dilution of the source material is inversely proportional to wind speed, e.g. if the wind speed doubled, the volume of air passing over a given area also doubled.

Equipment and supplies

The following items were procured for a full scale monitoring program:

- Two battery-operated programmable vacuum pumps.
- Rotameter for calibrating flow rate of pump.
- A cyclone unit for measuring PM_{10} particles (two were okay for the project).
- Cassettes for holding filter papers for TSP measurement.
- A cassette-holder arrangement with tubing and clip.
- 37mm diameter glass fibre filters: two packs of 100 pieces each.
- Balance with a minimum resolution of 0.1 mg and precision of 0.5 mg Class S calibration weights (1, 2 and 10 grams).
- A desiccator for conditioning or equilibrating filters and salt for maintaining proper relative humidity.
- Digital anemometer/thermometer.
- Plastic bag with zip lock edges bags (10" x 12").
- Laboratory notebook or log sheet.
- Black permanent pens.
- Powder-free gloves for handling filters and cassettes.

Precautionary measures

- Filters were handled using either vinyl or powder-free gloves. Filters were never touched with bare hands.
- All filters were inspected prior to pre-sampling weighing. Any filter with pinhole, tear, discoloration or dense spot, thin spot, or loose fiber was rejected. No fibre glass filter defect was detected during the monitoring program.
- The minimum balance resolution used for weighing the 37mm diameter filter was 0.1mg.

Specimen preparation

- After inspection, the filter was placed in a cassette and the whole arrangement placed in a zip lock bag. Each filter was conditioned, weighed, transported to and from the field, and stored in the same zip locked bag with the appropriate labeling using a permanent marker. All of the information on the label was also recorded in a laboratory notebook (or log sheet) and the Field Operation Form (Table 4).
- Filters were equilibrated for 24 hours prior to pre- and post-sampling weighing at a relative humidity of 37% ±5% and a temperature of 25^{o}C ±3^{o}C. Equilibration was carried out in a desiccator.
- After conditioning for 24 hours, the filters were removed from the desiccator and placed inside their respective zip locked bags.
- The balance was calibrated internally. Prior to weighing filters, the

internal calibration was validated using calibration weights (1, 2 and 10-gram weights). .

- The balance was tared with a cup placed on it. The filter (with cassette) was also placed in the cup for weighing. All weights were recorded in the Field Operation Form.

Quality assurance and quality control

The balance had to be re-tared (re-zeroed) prior to each filter weighing. After internal balance calibration, the balance had to be checked with an external weight. The balance was verified by using external calibration weights before and after each weighing session and every batch of ten TSP and PM_{10} filters. The results were recorded for each measurement in the laboratory notebook. The values for the calibration weights should not change by more than ± 0.0005g between the two verification readings.

Replicate filter weighing was performed for each batch of ten filters and each weighing session. For the first batch of ten filters, the first filter was re-weighed after the tenth filter. For pre-weighed filters, the replicate filter analysis was kept within ± 0.0025g. For post-weighed replicates, replicates were also kept within ± 0.0050g.

The samples were labeled as follows:

Type:	TSP or PM_{10}
ID. No.:	00 to 100
Date:	dd/mm/yy

Sample calculation for PM_{10}

The Field Operator had to perform initial and final verification flow rate check. These values were reported on the Verification Form. The average of these two values was used for the calculation below.

If the vacuum pump on the PM_{10} sampler operated at 5litres/min, then

C = X / Q.Y where,

C = mass concentration of PM_{10} particles in micrograms (*u*g)

X = PM_{10} pickup from filter in g

Q = 5litres/min = 0.005m^3/min

Y = time collected in minutes = (8 hr)(60 min/hr) = 480 minutes

If we had 0.0050g PM_{10} pick up = (0.0050g)(1000mg/g)(1000µg)/(l mg) = 5,000 µg

C = 5000µg /(0.005m^3/min X 480min)

C = 2,083µg/m^3 PM_{10} particles

Table 4: Field operation report for Ghacem welfare block (TSP monitoring)

Date	2/7/06	20/9/06	19/9/06	10/5/06
ID No.	B	D	B	H
Sampling duration, Y (hr)	8	8	8	8
1st Initial weight of Cassette, W_{1a} (g)	14.3783	14.3775	14.3823	14.3527
2nd Initial weight of Cassette, W_{1b} (g)	14.3781	14.3777	14.3825	14.3529
Ave. Initial weight of Cassette, W_1 (g)	14.3782	14.3776	14.3824	14.3528
1st Final weight of Cassette, W_{2a} (g)	14.3897	14.3873	14.3901	14.3600

Table 4: Field operation report for Ghacem welfare block (TSP monitoring)

2^{nd} Final weight of Cassette, W_{2b} (g)	14.3893	14.3875	14.3901	14.3602
Ave. Final weight of Cassette, W_2 (g)	14.3895	14.3874	14.3901	14.3601
Pickup from filter, X g $= W_2 - W_1$	0.0113	0.0098	0.0077	0.0073
Initial flow rate Q1, l/min	5.0	5.0	5.0	5.0
Final flow rate Q2, l/min	4.8	6.0	5.0	5.0
Average flow rate Q = (Q1+Q2)/2	4.9	5.5	5.0	5.0
TSP concentration C, *u*g	4,804	3,712	3,208	3042

Source: Field survey, 2007

Equipment siting requirement

As with any type of air monitoring study in which the sample data are used to draw conclusions about a geographical area, the validity of those conclusions depends on the representativeness of the sampling data. Therefore, the initial goal of the TSP and PM_{10} monitoring project was to select a safe and secured site where the measurements will be representative of the monitoring objectives for the site.

The sampler was placed well away from obvious sources of particles (e.g., fires, chimneys, engine exhausts) or air disturbance (e.g., fans, air conditioners, building exhausts, exhaust from other instruments). Each sampler was mounted on a stand to provide a base for the pump and shade for the filter arrangement which was set at a height of about 2 meters (Plate 1).

The following sampler location guidelines were observed:

- The sampler had unobstructed air flow for a minimum of 2m in all directions.
- If a PM_{10} sampler was collocated with TSP sampler, the spacing between sampler inlets was kept at least 2m.
- The siting of the PM sampler required the consideration of the prevailing wind direction.

Safety and security

The samplers were positioned at locations where the operator could easily reach them safely regardless of weather conditions. A locking arrangement was provided on the stand to secure the pump without impeding air flow across the site.

Sampling equipment installation procedure

Particle concentrations were measured by high-volume filter, where a large volume of air was pumped through it and the filter weighed to determine the particle concentration in the air. A digital controller allowed the operator to select a number of options to run. A non-re-settable digital elapsed timer reading to tenths of hours provided an independent estimate of the run time. If the circuitry detected that the flow had dropped too low (e.g., due to the filter becoming clogged), or a drop in the battery voltage below 10.5 volts, the sampler stopped and gave a corresponding LED to indicate the problem.

CHAPTER FOUR

RESULTS AND DISCUSSION

Introduction

In this chapter the results of the field investigation will be analyzed for trends and evaluated to determine whether the stated objectives of the study have been met. The results of the hypothesis will be presented and improvement measures aimed at mitigating the adverse environmental condition monitored will also be proposed.

Altogether forty-four TSP and their corresponding PM_{10} values were recorded for the dry season monitoring and another forty-four sets of data were compiled for the wet season monitoring campaign. The eleven sampling points (Plate 3) were selected to cover areas where operational activities were likely to generate aspects with significant impact on the environment (Appendix 5).

Climatological data covering the period July 2006 to January 2007 and comprising the predominant wind direction, average wind speed, rainfall, temperature and relative humidity were also compiled to give meaning to the dust measurement results.

In all the eleven sampling locations, the PM_{10} mean values for both dry and wet seasons far exceeded the EPA maximum emission value of $70\mu g/m^3$. The mean TSP values for both dry and wet seasons also exceeded the EPA permissible value of 230µg/m^3 in all the eleven sampling locations. At the Ghacem Welfare Block, both the mean PM_{10} and TSP values for wet season were 562 and 1425µg/m^3 higher than their corresponding mean values obtained during the dry season. This was also the case at the following sampling points:

- Fisheries
- Ghacem gate
- Between Packing plant–Takoradi Flour Mill
- Between Packing plant–Ghana Ports & Harbour Authority (GPHA)
- GPHA market
- Total/Shell Bitumen plants
- Takoradi Floor Mill entrance

From Appendix 5, it could generally be deduced that particulate matter air borne at the harbour industrial zone is either marginally affected or not affected by the weather pattern. From the climatological data, the relatively high wind speed (averaging 4.2 knots during the wet season compared with 2.2 knots in the dry season) could have diluted and doubled the source emissions during the wet season.

Concentrations of TSP airborne at the Harbour industrial area

The trend in Figure 5 can be explained by analyzing the linear model. The R^2 value of 3.54% indicated that the variation in TSP concentration during the dry season cannot be fully explained by the sampling locations. TSP concentrations recorded at each sampling location depended largely on the operational activity on-going at the time of measurement, wind direction and wind speed.

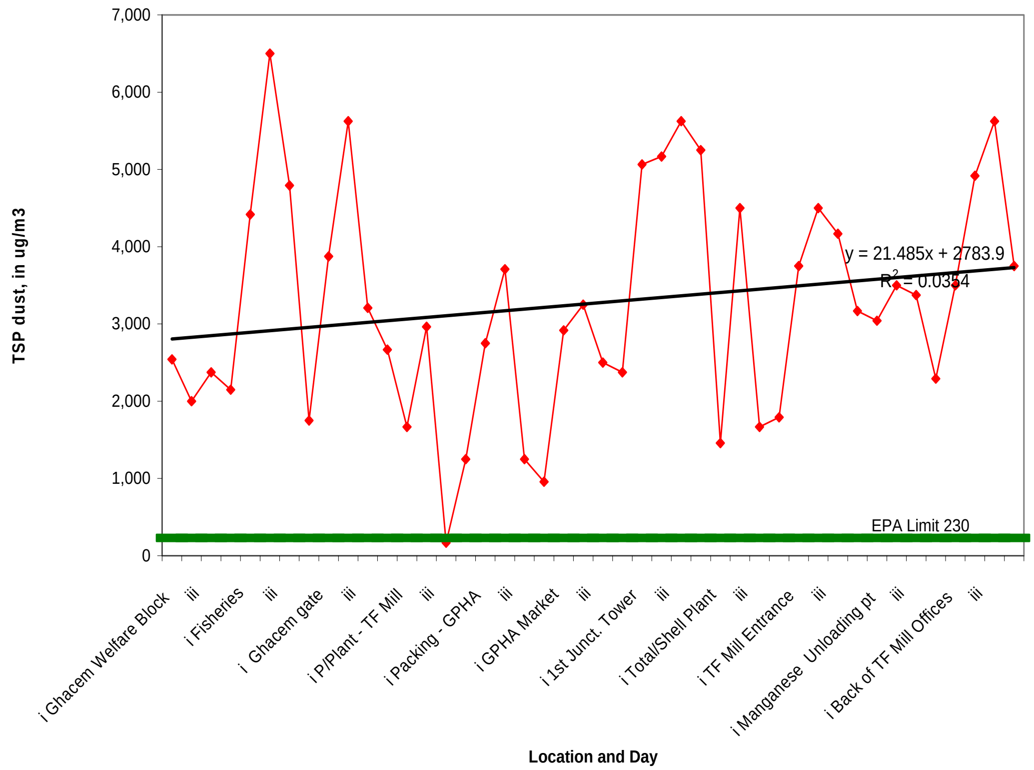

Figure 5: Plot of TSP values in µg/m^3 for dry season data

Source: Field survey, 2007

The lowest TSP value recorded during the dry period was 167µg/m^3 and the position was between Ghacem Packing Plant and Takoradi Floor Mill. The rather low value was due to the fact that there was no packing activity at the packing plant and there was virtually no vehicular movement on the dusty road nearby at the time of measurement.

At the 1st Junction Tower area, the values recorded were generally high (mean = 4,228) and this was due mainly to the dusty nature of the road. The highest TSP value of 7,292µg/m^3 recorded at the 1st Junction Tower may be due to dust emission from clinker discharge operation, the very dusty nature of the road (most of which resulted from bauxite spillage) at the time of monitoring. Figure 6 depicts TSP trends monitored during the wet season.

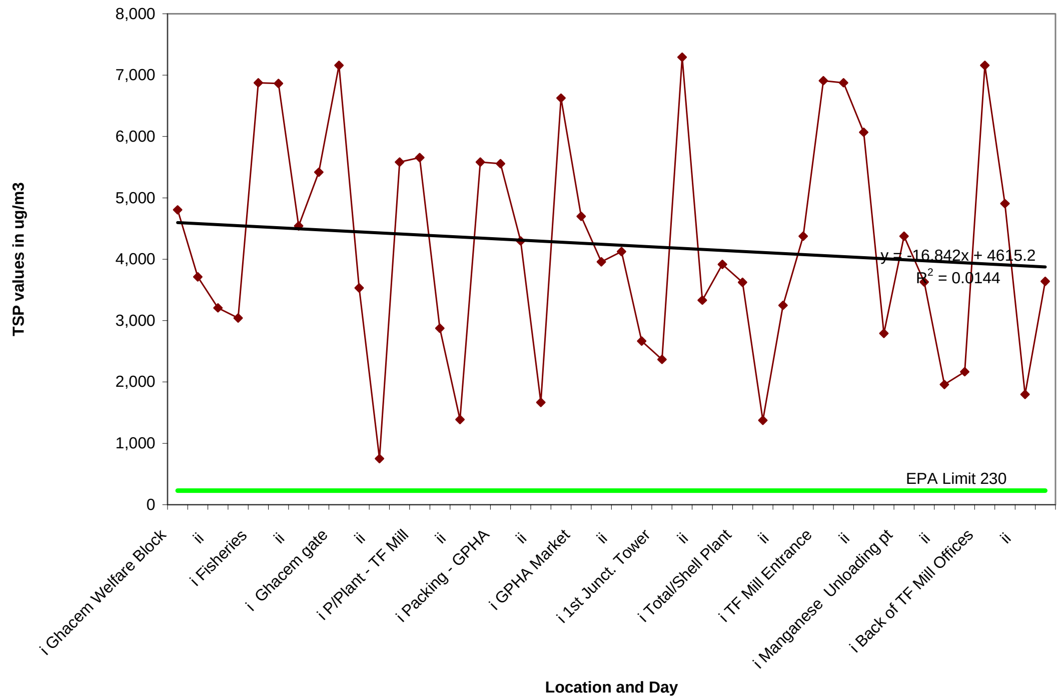

Figure 6: Plot of TSP values in μg/m^3 for Wet Season Data

Source: Field survey, 2007

Areas such as the Fisheries, Ghacem gate, the GPHA market, 1st Junction Tower, Takoradi Floor Mill Entrance and Back of Takoradi Floor Mill offices were points of high emissions exceeding 6,000μg/m^3 of particulate dust.

The dusty nature of the road from the GPHA market and encircling Ghacem Limited and extending as far as the 1st Junction area generates so much fugitive dust and this had significant effect on the dust measurements at these areas.

At the Entrance of Takoradi Flour Mill, the highest TSP value recorded during the wet season was 6,910µg/m^3. This could probably be due to the increased vehicular activities at the time of monitoring.

The lowest TSP value recorded during the wet season was 750µg/m3 and that was far higher than the EPA permissible value of 230µg/m3. This was recorded in front of the Ghacem gate. The rather low figure here could be attributed to the spraying of the road by a water tanker provided by Ghacem to suppress fugitive dust.

Concentrations of PM_{10} airborne at the Harbour industrial area

Figure 7 shows the PM_{10} trend of the sampled locations during the dry season. With the exception of only one measurement that registered a PM_{10} value of 58µg/m^3 (which was less than 70µg/m^3), all the values exceeded the permissible limit with the 1st Junction Tower recording the highest figure of 1,856µg/m^3.

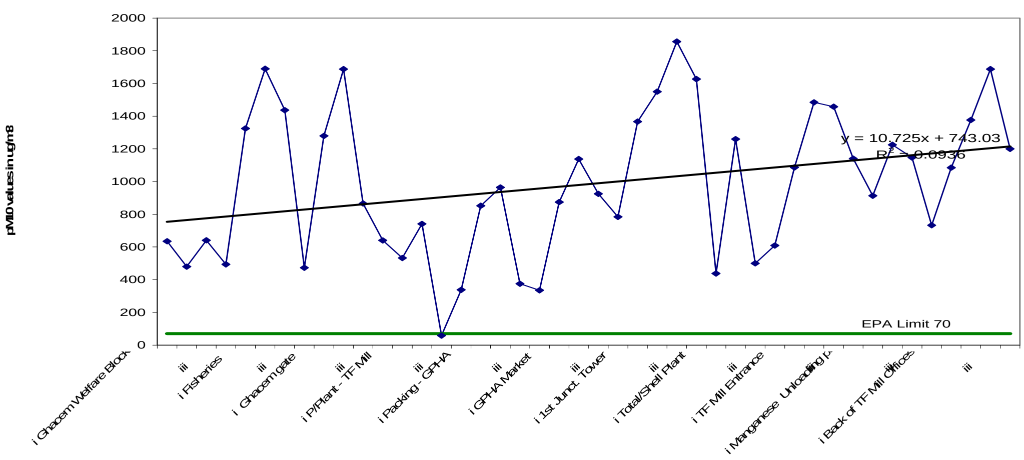

Figure 7: Plot of PM_{10} values in µg/m^3 for Dry Season Data

Source: Field survey, 2007

Figure 8 indicates that all the PM_{10} values recorded during the wet season were higher than the EPA Permissible Limit of 70µg/m^3. The lowest PM_{10} value recorded was 263µg/m3 and this was recorded at the Ghacem gate. This figure was about four times higher than the permissible value.

The highest PM_{10} value was 2,219µg/m3 and this was recorded at the Ghacem Gate. This high value could be due to secondary source emission arising from the dusty nature of the road in front of the gate.

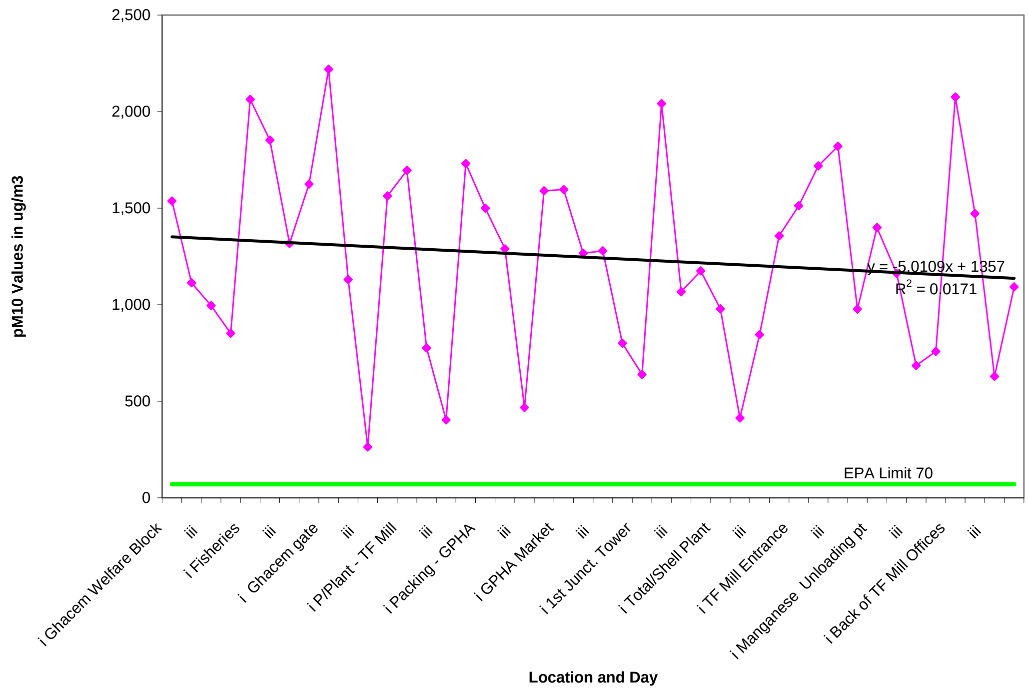

Figure 8: Plot of PM_{10} values in µg/m^3 for wet season data

Source: Field survey, 2007

Results of the hypothesis

This study sought to determine whether the mean dust emission levels for the various sampling locations in the Sekondi Takoradi Harbour Industrial area is within the EPA maximum permissible guideline limit of 230µg/m^3 for TSP values and 70µg/m^3 for PM_{10} values either in the dry season or the wet season. The decision approach interpretation which assumed a significance level of 5% (or alpha = 0.05) was used in testing the hypothesis. The Decision Rule for the test was that if the value in the Sig. (2-tailed) column is equal or less than 0.05, then there is a significant difference in the mean TSP or PM_{10} values and their corresponding permissible values.

Table 5: Interpretation of output from TSP Values t-test

	Test Value = 230					
	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
TSP Dry	13.726	43	0.000	3037.364	2591.10	3483.63
TSP Wet	14.725	43	0.000	4006.318	3457.64	4555.00

Source: Field survey, 2007

From Table 5, the hypothesis can be formulated for the TSP values recorded during the dry season as follows:

Ho: mean TSP for dry season ≤ 230

H_1: mean TSP for dry season > 230

Sig. (2-tailed) = 0.000 is less than alpha = 0.05, which implies that the mean difference is significant (in this case 3037.4). We reject the null hypothesis and conclude that the mean TSP for dry season is greater than the permissible value of 230.

Similarly, for the TSP values recorded during the wet season,

Ho: mean TSP for wet season ≤ 230

H_1: mean TSP for wet season > 230

Sig. (2-tailed) = 0.000 is less than alpha = 0.05, which implies that the mean difference is significant (in this case 4006.3). We reject the null hypothesis and conclude that the mean TSP for wet season is higher or greater than the permissible value.

From Table 6, the hypothesis can also be formulated for the PM_{10} values recorded during the dry season as follows:

Ho: mean PM_{10} for dry season ≤ 70

H_1: mean PM10 for dry season > 70

Sig. (2-tailed) = 0.000 is less than alpha = 0.05, and this implies that the mean difference is significant (in this case 914.4). We reject the null hypothesis and conclude that the mean PM_{10} value for dry season is greater than the permissible value of 70.

Similarly, for the PM_{10} values recorded during the wet season,

Ho: mean PM_{10} for wet season ≤ 70

H_1: mean PM_{10} for wet season > 70

Table 6: Interpretation of output from PM_{10} Values t-test

	Test Value = 70					
	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
PM10 Dry	13.472	43	0.000	914.364	777.49	1051.24
PM10 Wet	15.821	43	0.000	1174.614	1024.89	1324.34

Source: Field survey, 2007

Sig. (2-tailed) = 0.000 is less than alpha = 0.05, which implies that the mean difference is significant (in this case 1,174.6). We thus reject the null hypothesis and conclude that the mean PM_{10} for wet season is greater than the permissible value.

Table 7 is the output of the combination of all the TSP data for both wet and dry seasons. In this case N becomes 88.

For an alpha = 0.05,

$t_{critical} = 1.6955$

Table 7: Interpretation of output from TSP wet and dry values t-test

	Test Value = 230					
	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
TSP Dry & Wet	19.360	87	0.000	3521.841	3160.27	3883.41

Source: Field survey, 2007

For all TSP values, the hypothesis is presented thus,

Ho: mean TSP for all seasons ≤ 230

H_1: mean TSP for all seasons > 230

From Table 7, $t_{calculated\ TSP} = 19.360$. This is more than $t_{critical}$ so we reject the null hypothesis and state that the mean TSP for all seasons was greater than the EPA permissible value of 230µg/m^3.

Table 8 is also the output of the combination of all the PM_{10} values for both wet and dry seasons. The hypothesis is also presented thus,

Ho: mean PM_{10} for all seasons ≤ 70

H_1: mean PM_{10} for all seasons > 70

From Table 8, $t_{calculated\ PM10} = 20.119$. This is more than $t_{critical}$ so we reject the null hypothesis and state that the mean PM_{10} for all seasons was greater than the EPA permissible value of 70µg/m^3.

Table 8: Interpretation of output from PM_{10} wet and dry values t-test

	Test Value = 70					
	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
PM_{10} Dry & Wet	20.119	87	0.000	1044.489	941.30	1147.68

Source: Field survey, 2007

Additionally, it is worthwhile to use the Paired Sample t-test to test for no difference in the dry and wet values recorded for both TSP and PM10. The result is displayed in Table 9.

The Null and Alternate Hypotheses are given by the following statement for Pair 1:

H_o: mean TSP dry = mean TSP wet

H_I: mean TSP dry ≠ mean TSP wet

Sig. (2-tailed) = 0.004 is less than alpha = 0.05, which implies that the mean difference is significant (in this case -969.0). We thus reject the null hypothesis and conclude that there is significant difference in TSP measurements taken during the dry and the wet seasons.

Table 9: Interpretation of output of Paired Sample t-test

		Paired Differences							
		Mean	Std. Dev.	Std. Error Mean	95% Confidence Interval of the Difference		t	df	Sig. (2-tailed)
					Lower	Upper			
Pair 1	TSP Dry – TSP Wet	-969.0	2126.3	320.6	-1615.4	-322.5	-3.023	43	0.004
Pair 2	PM10 Dry - PM10 Wet	-260.3	595.9	89.8	-441.4	-79.1	-2.897	43	0.006

Source: Field survey, 2007

Similarly for Pair 2:

Ho: mean PM_{10} dry = mean PM_{10} wet

H_I: mean PM_{10} dry ≠ mean PM_{10} wet

Sig. (2-tailed) = 0.006 is less than alpha = 0.05, which implies that the mean difference is significant (in this case -260.3). We reject the null hypothesis and conclude that there is significant difference in dust measurements taken during the dry and the wet seasons for PM_{10}.

Measures to improve operating and management practices

Industries within the Harbour Industrial area undoubtedly have one form of environmental management system or the other. The effectiveness of the management system depends largely on commitment shown by Top Management in providing resources and leading the way. The declaration of a policy can also be a driving force in bringing all stakeholders to take environmental issues more serious than has been done in the past. For the study area in particular, it is envisaged that the GPHA as the custodian of the area should lead in the campaign to ensure environmental performance, especially in ensuring that dusty roads within the area are tarred.

In proposing measures to improve operating and management practices to minimize dust emissions at the harbour industrial area, the quality circle model adopted in Chapter 2 as the conceptual framework for the study should be used. In this case planning will involve:

- Identifying all point sources of emission and ambient conditions
- Identifying opportunities for improvement by defining objectives and setting targets for the aspects identified
- Establishing EPA guidelines or standards for monitoring and controlling TSP and PM_{10}
- Developing environmental management programs with resources, responsibilities and deadlines to achieve them

The "Do stage" will entail implementing and operating the actions taken in the planning stage and this involves:

- Assigning responsibility throughout the company
- Embarking on training, awareness and competence development
- Communicating externally and internally throughout the company
- Developing operational controls for those environmental aspects with significant impacts
- Developing emergency preparedness and response with corrective and preventive actions for aspects that are likely to occur and those with the potential to occur

Creating awareness among the various levels of the workforce by communication and training will create the framework for all interested parties to join the wagon and participate fully in solving environmental issues.

In the “Checking stage”, the environmental performance is monitored by measuring and comparing results with EPA standards or benchmarked with peers in the industry. This is where audits are carried out to verify conformance to the environmental management system. Auditing can be done internally by trained personnel or by external qualified personnel. Auditing often leads to management review where changes can be made to the system, processes, procedures, objectives and targets and management programs.

There should also be proper documentation and control of documents and records in order to promote the right feedback mechanism when changes are made.

The “act stage” somehow integrates the whole cycle and prepares the ground for further improvement by setting new targets. The importance of meeting standards and environmental performance must be communicated to all stakeholders. The setting of new targets must reflect continuing improvements in performance. Training and other supports must also be provided by management to ensure continuity and prevent the EMS system breakdown. The cycle thus continues until the company achieves its target of 100% compliance.

It is best in this context to generalize issues rather than delve into individual companies operational activities to try to propose solutions for dealing with their environmental issues. This will constitute a research topic on its own. Opting for alternative production processes will depend largely on the availability of capital for investment and the financial performance of the company. Nevertheless this section will offer suggestions that management could opt for to enhance their environmental performance and competitiveness.

Management measures such as improved operating procedures incorporating operational controls which seek to address significant environmental aspects to reduce or eliminate their impacts is one sure way of dealing with this issue. Strict adherence to maintenance practices also ensures healthy operation devoid of excesses that tend to pollute the environment. By using the "5S method" one can create a workplace that is cleaner and safer to render job activities more satisfying and simpler. The 5S method is a reference to five words for the basic elements of this system: Sort, Set in order, Shine, Standardize and Sustain. A thorough implementation of the five pillars of 5S is the starting point in the development of improvement activities to ensure any company's survival.

The choice of fuel is either influenced by economic or environmental considerations. In minimizing the impact of atmospheric particulate emissions, selecting cleaner fuels can be the best option; the only constraint being the additional cost for rejecting heavier residual oils.

The use of more efficient technologies or process changes can increase production, improve quality and enhance environmental performance. Aged technologies have outlived their usefulness and should pave way for new technologies that can bring in its trail new product developments for cutting edge companies.

CHAPTER FIVE

SUMMARY, CONCLUSIONS AND RECOMMNEDATIONS

Summary

Over the past twenty years, air quality has improved appreciably in most cities in Western Europe, North America, and Japan. This is an encouraging example of improvement in environmental conditions. The success of humankind in controlling some of the most serious air pollutants gives us hope for similar progress in other environmental problems.

While developed countries have been making progress, however, air quality in the developing world such as Africa has not been improved. This is especially so in developing countries such as Ghana, where air pollution often exceeds World Health Organization standards.

The study investigated and evaluated the releases of particulate matter (both TSP and PM_{10}) from industrial activities within the Takoradi Port Industrial Area. The harbour industrial area as the centre of industrial activities is a major source of air pollution. The major pollutant is dust emission resulting from the activities of the following industrial establishments: Ghacem, Takoradi Flour Mills, Ghana Bauxite Company and Ghana Manganese Company.

The study area was subdivided according to the nature of operation and by sampling points. The study monitored ambient air around these locations as have been identified in the location map of the harbour industrial area. Samples were taken to determine the concentration of dust pollutant. The determination or analysis of the constituents of dust pollutants sampled was outside the scope of this study.

Although the study also recognized serious health implications associated with particulate matter pollution especially fine dust (PM_{10}) particles, the focus was to determine the extent of pollution and to propose mitigation measures that will help minimize or eliminate the dust pollutant from the environment so that workers, customers, visitors and neighbours alike would enjoy and breathe unpolluted air. The effects of particulate matter pollution on health can therefore be taken as a separate project.

The application of some of the tenets of Total Quality Management (TQM) is considered more appropriate in this study than any other concept. This is because the study is dealing with heavy industries which by law are expected to meet certain legislative requirements, demonstrate environmental consciousness in their operations and ensure the sustenance of social interactions with neighbours for the maintenance of good corporate image. Many of the features of effective environmental management are indistinguishable from the sound management practices advocated by proponents of TQM. The research therefore adopted the total quality framework and quality tools and techniques in addressing the environmental processes.

In addition to the air monitoring data, climatological data of the study area was also compiled from July 2006 to January 2007. In all the eleven sampling locations, the PM_{10} mean values for both dry and wet seasons far exceeded the EPA maximum emission value of 70µg/m^3. The mean TSP values for both dry and wet seasons also exceeded the EPA permissible value of 230µg/m^3 in all the eleven sampling locations.

Conclusions

In all the eleven sampled locations, the PM_{10} mean values for both dry and wet seasons far exceeded the EPA maximum emission value of 70µg/m^3. The mean TSP values for both dry and wet seasons also exceeded the EPA permissible value of 230µg/m^3 in all the eleven sampled locations.

From the hypothesis, it can be concluded that TSP concentration levels at the Takoradi harbour industrial area far exceeded the EPA permissible limit. Similarly, PM_{10} also had concentration levels at the same area exceeding the EPA permissible limit.

There was significant variation in dust emission during the wet season and the dry season. The doubling effect of the wind during the wet season as a result of higher wind speed also had significant effect on the monitoring results when compared with that of the dry season.

The dusty nature of the road from the GPHA market and encircling Ghacem Limited and extending as far as the Shell Bitumen Plant area generates so much fugitive dust and this had significant effect on the dust measurements at these areas. Any good monitoring exercise will have to factor in the dusty road before proper assessment can be made.

Management measures such as improved operating procedures incorporating operational controls purposely to address identified significant environmental aspects to reduce or eliminate their impacts is one sure way of controlling dust emission.

Strict adherence to maintenance practices also ensures that plant equipment performs excellently without breakdowns and that they do not result in any residual matter that is eventually disposed of into the environment.

The choice of fuel which is either influenced by economic or environmental considerations can considerably minimize the impact of atmospheric particulate emissions when cleaner fuels are opted for. The use of more efficient technologies or process changes can increase production, improve quality and enhance environmental performance. Aged technologies that have outlived their usefulness should and must give way to newer technologies that can bring in its trail new product developments for cutting edge companies.

Recommendations

It is not possible to describe the nature of the contaminants sampled in this study since this was outside the scope. It is therefore difficult to attribute a higher value of contaminant to any one company as being responsible for the pollution at the Takoradi harbour area.

In order to determine the actual contaminant and its source of emission, the ambient condition and the dusty roads must be isolated before chemical analysis are performed on samples collected.

In dealing with alternative production processes and technologies that can bring about significant reduction of dust emissions at the study area, it will be very necessary to collect data and information on existing control systems and management strategies from industries within the study area. This aspect of the study will constitute another research work.

Companies operating within the harbour area must take pragmatic measures to minimize their particulate matter emissions into the atmosphere. These measures must first be preceded by (if not already done) an initial environmental review to determine the current environmental status of each of the companies contributing to the pollution load. Internal standards should also be set based on the prevailing legal requirements and other international applicable standards. Thereafter an environmental gap analysis can be determined and the requisite action plan developed to close the identified gaps. This will of course depend on top management commitment and the level of influence exerted by regulatory bodies.

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APPENDICES

APPENDIX 1

TSP LEVELS WITHIN AND AROUND GHACEM TAKORADI (μG/M^3)

Location	No clinker discharge			Clinker discharge		
	1995	**2000**	**2004**	**1995**	**2000**	**2004**
Takoradi Flour Mill	-	-	222	-	-	780
Elf/Shell Bitumen Plant	160	125	296	13200	85	330
Ghacem Welfare Block	195	145	148	165	125	180

Source: Author's construct, 2006

APPENDIX 2

PM_{10} LEVELS WITHIN AND AROUND GHACEM TAKORADI ($\mu G/M^3$)

Location	No clinker discharge	Clinker discharge
Takoradi Flour Mill	74	180
Elf/Shell Bitumen Plant	63	165
Ghacem Welfare Block	74	95

Source: Author’s construct, 2006

APPENDIX 3

MEDICAL CONDITIONS OF THE STUDY AREA

HEIDELBERGCEMENT Group

THE FIVE TOP DISEASES

TOTAL CASES

	2004	2005	2006
MALARIA	386	440	410
RHEUMATISM & JOINT PAIN	284	275	243
RESPIRATORY TRACT INFECTION	218	235	198
SKIN DISEASES AND ULCERS	175	169	147
ACUTE EYE INFECTION	68	72	53

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TWIN CITY CLINIC

Various disease of out patients attendance of Takoradi Flour Mill from the year 2004 to 2006

DISEASE	YEAR		
	2004	2005	2006
MALARIA	623	734	786
RTI	81	97	101
SKIN DISODERS	86	96	123
WAIST & JOINTS PAINS	106	126	210
CARDIOVASCULAR DISODERS	96	102	112
EYE DISODERS	41	32	50

THE MEDICAL OFFICER IN CHARGE
TWIN CITY CLINIC
P. O. BOX 98
TAKORADI

12-08-2008

2005-6 Medical conditions compared to 2004 cases for staff of Ghacem & Takoradi Flour Mill

	Ghacem Limited workers		Takoradi Flour Mill workers	
	2005	2006	2005	2006
RTI	-7.9%	9.2%	-19.8%	24.7%
Skin Diseases	3.4%	16.0%	-11.6	-43.0%
Eye Infection	-5.9%	22.1%	22.0%	-22.0

APPENDIX 4

CLIMATOLOGICAL DATA FOR TAKORADI

PERIOD: JULY 2006 - JAN 2007

Month	**Rainfall (mm)**	**Temp (^oC) Max/Min**	**Relative Humidity %**	**Wind Speed kts**	**Wind Direction**
Jul-06	132.2	882.9	2689	12.2	variability
		28.5	87	3.9	
August	30.9	861.1	270.1	14.2	southwest
		27.8	87	4.6	
September	84.2	857.0	2668	131	southwest
		28.6	89	4.4	
October	252.3	922.6	2667	123	southwest
		29.8	86	4.0	
November	45.8	934.7	2519	77	southwest
		31.1	84	2.4	

December	10.4	980.9	271.7	75	southwest
		31.6	88	2.4	
Jan. 2007	0.2	978.6	2530	59	variability
		31.6	82	1.9	

Meteorological Services Department Sekondi, 2007

APPENDIX 5

TSP – PM_{10} CONCENTRATIONS IN WET AND DRY SEASONS

Location	PM_{10} Values in ug/m3				TSP Values in ug/m3			
	Date	DRY SEASON	Date	WET SEASON	Date	DRY SEASON	Date	WET SEASON
Ghacem Welfare Block	06/12/06	635	02/07/06	1,537	06/12/06	2,542	02/07/06	4,804
	13/12/06	480	20/09/06	1,114	13/12/06	2,000	20/09/06	3,712
	20/12/06	641	19/09/06	995	20/12/06	2,375	19/09/06	3,208
	21/12/06	494	05/10/06	852	21/12/06	2,149	05/10/06	3,042
Mean		**563**		**1,125**		**2,267**		**3,692**
	08/12/06	1,325	26/07/06	2,063	08/12/06	4,417	26/07/06	6,875

Fisheries								
	18/12/06	1,690	20/09/06	1,853	18/12/06	6,500	20/09/06	6,863
	19/12/06	1,437	19/11/06	1,317	19/12/06	4,792	19/11/06	4,542
	29/12/06	473	05/10/06	1,625	29/12/06	1,750	05/10/06	5,417
Mean		**1,231**		**1,715**		**4,365**		**5,924**
cont'd TSP – PM_{10} CONCENTRATIONS IN WET AND DRY SEASONS								
Ghacem gate	13/12/06	1,279	26/07/06	2,219	13/12/06	3,875	26/07/06	7,159
	18/12/06	1,688	04/08/06	1,130	18/12/06	5,625	04/08/06	3,532

	19/12/06	866	29/09/06	263	19/12/06	3,208	29/09/06	750
	29/12/06	640	17/10/06	1,563	29/12/06	2,667	17/10/06	5,583
Mean		**1,118**		**1,294**		**3,844**		**4,256**
P/Plant - Tak Flour Mill	08/12/06	533	31/07/06	1,696	08/12/06	1,667	31/07/06	5,655
	14/12/06	741	21/09/06	776	14/12/06	2,963	21/09/06	2,875
	07/01/07	58	01/11/06	403	07/01/07	167	01/11/06	1,389
	10/01/07	338	02/11/06	1,731	10/01/07	1,250	02/11/06	5,583
Mean		**417**		**1,152**		**1,512**		**3,876**

	cont'd TSP – PM_{10} CONCENTRATIONS IN WET AND DRY SEASONS							
Packing GPAH	06/12/06	852	01/08/06	1,500	06/12/06	2,750	01/08/06	5,556
	14/12/06	964	02/09/06	1,289	14/12/06	3,708	02/09/06	4,298
	20/12/06	375	01/11/06	467	20/12/06	1,250	01/11/06	1,667
	21/12/06	335	02/12/06	1,590	21/12/06	958	02/11/06	6,625
Mean		**632**		**1,212**		**2,167**		**4,537**
	12/12/06	875	01/08/06	1,597	12/12/06	2,917	01/08/06	4,698

GPHA Market								
	16/12/06	1,138	24/10/06	1,267	16/12/06	3,250	24/10/06	3,958
	11/01/07	925	29/09/06	1,279	11/01/07	2,500	29/09/06	4,125
	1701/07	784	31/10/06	800	17/01/07	2,375	31/10/06	2,667
Mean		**931**		**1,236**		**2,761**		**3,862**

TSP – PM_{10} CONCENTRATIONS IN WET AND DRY SEASONS

Location	PM_{10} Values ug/m3				TSP Values in ug/m3			
	Date	DRY SEASON	Date	WET SEASON	Date	DRY SEASON	Date	WET SEASON

1st Junction Tower	10/12/06	1,367	04/08/06	639	10/12/06	5,065	04/08/06	2,368
	17/12/06	1,550	25/09/06	2,042	17/12/06	5,167	25/09/06	7,292
	11/01/07	1,856	14/10/06	1,067	11/01/07	5,627	14/10/06	3,333
	17/01/07	1,627	18/10/06	1,175	17/01/07	5,250	18/10/06	3,917
Mean		**1,600**		**1,231**		**5,277**		**4,228**
Total/Shell Plant	10/12/06	438	08/07/06	979	10/12/06	1,458	08/12/06	3,625
	17/12/06	1,260	25/09/06	413	17/17/06	4,500	25/09/06	1,375

	01/12/07	500	14/10/06	845	01/12/07	1,667	14/10/06	3,250
	19/01/07	609	18/10/06	1,356	19/01/07	1,792	18/10/06	4,375
Mean		**702**		**898**		**2,354**		**3156**
	cont'd TSP – PM_{10} CONCENTRATIONS IN WET AND DRY SEASONS							
	07/12/06	1,087	08/07/06	1,513	07/12/06	3,750	08/07/06	6,910
TF Mill	15/12/06	1,485	26/07/06	1,719	15/12/06	4,500	26/07/06	6,875

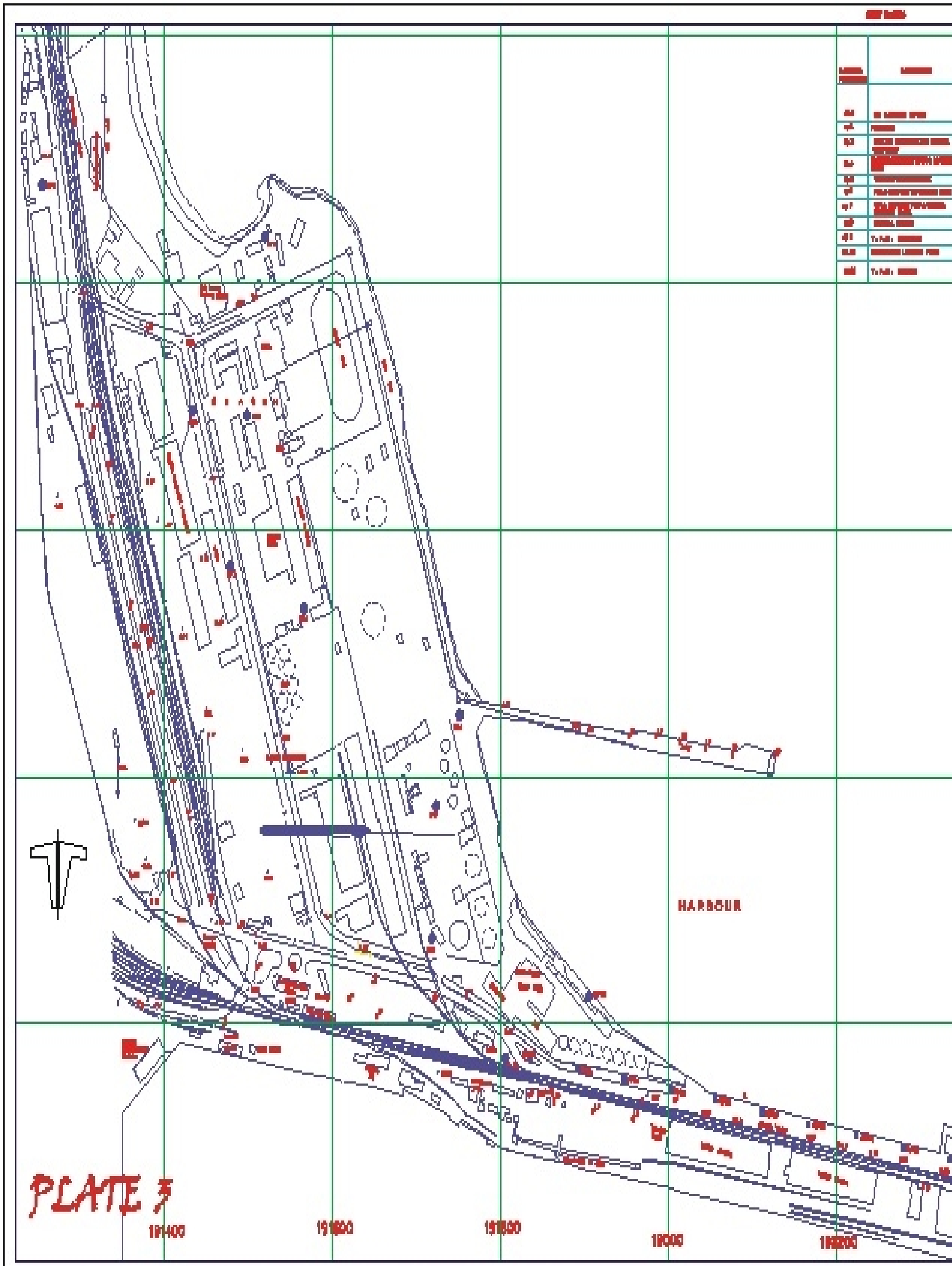
Entrance								
	01/12/07	1,458	26/09/06	1,821	01/12/07	4,167	26/09/06	6,069
	19/01/07	1,140	23/10/06	977	19/01/07	3,167	26/10/06	2,792
Mean		**1,293**		**1,507**		**3,896**		**5,662**
Manganese Unloading Point	12/12/06	913	17/10/06	1,400	12/12/06	3,042	17/10/06	4,375
	16/12/06	1,225	24/10/06	1,162	16/12/06	3,500	24/10/06	3,630
	15/01/07	1,147	25/10/06	685	15/01/07	3,375	25/10/06	1,958
	24/01/07	733	26/10/06	758	24/10/07	2,292	26/10/06	2,167

Mean		**1,005**		**1,001**		**3,052**		**3,003**
	cont'd TSP – PM_{10} CONCENTRATIONS IN WET AND DRY SEASONS							
	07/12//06	1,085	26/07/06	2,076	07/12/06	3,500	26/07/06	7,159
Back of TF Mill	15/12/06	1,377	26/09/06	1,472	15/12/06	4,917	26/09/06	4,907

Offices	15/01/07	1,688	25/10/06	629	15/01/07	5,625	25/10/06	1,798
	24/01/07	1,200	31/10/06	1,092	24,01/07	3,750	31/10/06	3,640
Mean		**1,338**		**1,317**		**4,448**		**4,376**

Plate 1: A TSP sampler mounted at Ghacem Welfare Block to monitor Total Suspended Particulates

Plate 2: Flow rates of sampling pumps being verified after sampling operation.



LOCATIONAL MAP FOR HARBOUR INDUSTRIAL AREA