THE UNIVERSITY OF ZAMBIA

SCHOOL OF ENGINEERING

DEPARTMENT OF MECHANICAL ENGINEERING

ME 590 FINAL YEAR PROJECT

TO DETERMINE THE LEVELS AND IMPACT OF AIR POLLUTION IN LUSAKA

NAME: KAMANGU HAMUNA

COMP#: 22034102

APRIL 2010

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"Report submitted in partial fulfillment of the requirement for the award of the Degree of Bachelor of Engineering, University of Zambia".

APRIL 2010

Dedication

To dad,

For your unconditional love, ceaseless support and making this world a better place.

ACKNOWLEDGEMENTS

It is a great pleasure to acknowledge the people who contributed their support, time and physical energy to this project. Foremost, I acknowledge the inestimable guidance, advice and encouragement PROF F.D. YAMBA ceaselessly provided throughout this study, which spanned for a year.

I also acknowledge the help rendered by Dr P.C. Chisale, for the expertise in pollution study and Mr. E. Luwaya for the expertise in numerical computations. I also extend my gratitude to my friends and colleagues, with whom I shared many wonderful experiences and friendly diversions.

All this work would have been neither possible nor meaningful without the understanding, patience and unflagging support from my family and my parents. I finally dedicate this work to my late mother whose dream of a better future still lives in me.

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CHAPTER ONE

Introduction

1.1 BACKGROUND

A few decades ago, a project entitled "To investigate the levels and impact of air pollution in Lusaka" would have attracted less attention. On the contrary, today when the word pollution is mentioned almost everyone, from the child in primary school to a professor at a university, appreciates that we are talking about a significant problem affecting all society. The Engineers' Joint Council in "Air Pollution and Its Control" defines air pollution as the presence in the outdoor atmosphere of one or more contaminants, such as dust, fumes, gas, mist, odor, smoke, or vapor in quantities, of characteristics, and of duration, such as to be injurious to human, plant, or animal life or to property, or which unreasonably interferes with the comfortable enjoyment of life or property (Henry. C. Perkins, 1974).

Lusaka being a capital city is a centre of trade, and thus production and manufacturing industries are many as the market for the products is readily available. Lusaka residents' desire for comfort and wealth, along with the explosion in population, has also put pressure on the industrialist to produce more. It is evident that in both developed and developing countries a relationship between population growth and air pollution levels exists. This relationship is of course direct and shows that a high population growth brings about high pollution levels. Table 2.1 shows estimates of the population growth of Zambia.

Table 1.1. Population growth (Zambia)

Population growth rate	1.65 percent (2008 estimate)
Projected population in 2025	14,829,985 (2025 estimate)
Projected population in 2050	18,435,053 (2050 estimate)
Population density	16 persons per sq km (2008 estimate)

Source: Microsoft ® Encarta ® 2009. © 1993-2008 Microsoft Corporation.

Of course increased industrial productivity and activity leads to more air pollution. In view of this, this project seeks only to assess the levels of air pollutants in Lusaka and then compare with the acceptable levels. If the measured levels are found to be above the acceptable levels, reasonable and appropriate measures to reduce the levels will be suggested and documented in the project report. Also if the measured levels are found to be below the acceptable levels, reasonable and appropriate measures to maintain the low levels will be suggested and documented.

In this project report, many pollution related terms have been referred to, therefore it is vital that they are explained beforehand in line with the environmental council of Zambia (ECZ) definitions.

I. "Ambient air" means the atmosphere surrounding the earth, but does not include the atmosphere within a structure or within any underground space.
II. "Air quality" means the concentration of a pollutant in the atmosphere at the point of measurement.
III. "Emission standard" means the amount of pollutant emitted from a specific source.
IV. "Pollutant" means any substance or energy which if it enters or is discharged into the ambient air is likely to render the air offensive or harmful to human, animal or plant life.
V. "Stationary source" means any source of emission of one or more pollutants other than a motor vehicle, ship, train, aircraft, or other similar vehicle or conveyance.

It is then also important that the pollutants under investigation are identified and described;

I. Carbon Monoxide
II. Sulphur Oxides
III. Nitrogen Oxides

The gases above are discussed in detail below;

Carbon monoxide

Carbon monoxide is a colorless and tasteless gas that is poisonous to humans in high concentrations. CO is a trace constituent in the atmosphere, produced by both natural processes (e.g. Volcanoes) and human activities, (e.g. the incomplete combustion of carbon- containing fuels).

Adverse effects

CO affects human health by reducing the amount of oxygen that can be carried in the blood to the body tissues. When inhaled, CO combines with haemoglobin (Hb), the blood's oxygen carrying protein molecule, to form carboxyhaemoglobin (COHb). In this state the Hb is unable to carry oxygen.

CO levels are of concern from a human health perspective if they exceed recommended air quality guidelines, which are generally based on a No Observed Adverse Effect Level of 2.5% carboxyhaemoglobin in blood (http//edugreen.teri.res.in/health.html).

Nitrogen dioxide

In the high temperature zones of combustion processes, nitrogen in air and in the fuel reacts with oxygen in air to form nitrogen oxides: nitric oxide (NO), nitrogen dioxide (NO_2), and nitrous oxide (N_2O). These are collectively referred to as NO_x gases. For most combustion processes nitrogen oxides are emitted primarily in the form of NO, which slowly oxides to NO_2 in the atmosphere. Nitrogen dioxide is a pungent, acidic, reddish-brown gas, that is corrosive and strongly oxidizing.

Adverse effects

NO_2 in the human respiratory system causes increases in both the susceptibility to and the severity of infections and asthma.

NO_2 is a significant pollutant not only because of the health effects it directly causes, but also as a result of the role it can play in the generation of photochemical smog events and the production of secondary particles that cause visibility degradation.

Sulphur Dioxide

Sulphur dioxide is colorless, soluble gas with a characteristic pungent smell. It reacts with water in air to form sulphuric acid aerosol (H_2SO_4).

Adverse effects

SO_2 is a potent respiratory irritant when inhaled and high ambient levels of SO_2 are hazardous to health.

Carbon Dioxide

Carbon dioxide has been included under this study because of its hazardous effects as a green house gas. Carbon dioxide is a natural constituent of the atmosphere. However, the artificial production of the gas through fossil fuel combustion increases its atmospheric concentrations. These increased levels bring about global warming and subsequently climate change. For this reason carbon dioxide is considered more of a green house gas than a pollutant.

Adverse effects

The adverse effects of carbon dioxide are basically those associated with climate change such as; droughts, desertification, high atmospheric temperatures and floods.

The pollutants discussed above are products of combustion which is explained in brief below;

Combustion or **burning** is the sequence of exothermic chemical reactions between a fuel and an oxidant accompanied by the production of heat and conversion of chemical species. The release of heat can result in the production of light in the form of either glowing or a flame. Fuels of interest often include organic compounds (especially hydrocarbons) in the gas, liquid or solid phase. Products of combustion are released as shown in the figure below.

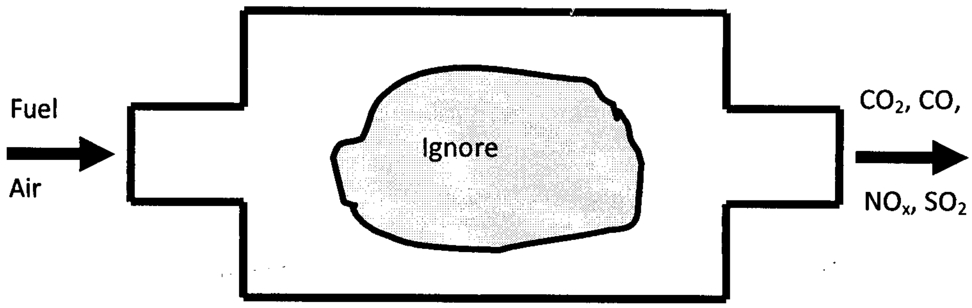


Figure 1.1- Combustor

Types of combustion

Complete combustion

In complete combustion, the reactant will burn in oxygen, producing a limited number of products. When a hydrocarbon burns in oxygen, the reaction will only yield carbon dioxide and water. When a hydrocarbon or any fuel burns in air, the combustion products will also include nitrogen. When elements such as carbon, nitrogen, sulfur, and iron are burned, they will yield the most common oxides. Carbon will yield carbon dioxide. Nitrogen will yield nitrogen dioxide. Sulfur will yield sulfur dioxide. Iron will yield iron (III) oxide. It should be noted that complete combustion is almost impossible to achieve. In reality, as actual combustion reactions come to equilibrium, a wide variety of major and minor species will be present. For example, the combustion of methane in air addition to the major products of carbon dioxide and water, the minor side reaction products carbon monoxide and nitrogen oxides.

In a complete combustion reaction, a compound reacts with an oxidizing element, such as oxygen or fluorine, and the products are compounds of each element in the fuel with the oxidizing element. For example:

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O + \text{energy} \qquad \text{Eqn 1.1}$$

$$CH_2S + 6F_2 \rightarrow CF_4 + 2HF + SF_6 \qquad \text{Eqn 1.2}$$

A simpler example can be seen in the combustion of hydrogen and oxygen, which is a commonly used reaction in rocket engines:

$$2H_2 + O_2 \rightarrow 2H_2O\ (g) + \text{heat} \qquad \text{Eqn 1.3}$$

The result is water vapor.

In the large majority of industrial applications of combustion and in fires, air is the source of oxygen (O_2). In air, each kg of oxygen is mixed with approximately 3.76 kg of nitrogen. The resultant flue gas from the combustion will contain nitrogen:

$$CH_4 + 2O_2 + 7.52N_2 \rightarrow CO_2 + 2H_2O + 7.52N_2 + \text{heat} \qquad \text{Eqn 1.4}$$

Incomplete combustion

When hydrocarbon burns in air, the reaction yields carbon dioxide, water, carbon monoxide, pure carbon (soot or ash) and various other compounds such as nitrogen oxides. Incomplete combustion occurs when there isn't enough oxygen to allow the fuel to react completely with the oxygen to produce carbon dioxide and water, and also when the combustion is quenched by a heat sink such as a solid surface or flame trap.

The quality of combustion can be improved by design of combustion devices, such as burners and internal combustion engines. Further improvements are achievable by catalytic after-burning devices (such as catalytic converters) or by the simple partial return of the exhaust gases into the combustion process. Such devices are required by environmental legislation for cars in most countries, and may be necessary in large combustion devices, such as thermal power plants, to reach legal emission standards.

The degree of combustion can be measured and analyzed, with test equipment. HVAC contractors, firemen and engineers use combustion analyzers to test the efficiency of a burner during the combustion process. In addition, the efficiency of an internal combustion engine can be measured in this way, and some states and local municipalities are using combustion analysis to define and rate the efficiency of vehicles on the road today (R.M.E. Diamant, 1974).

Smoldering combustion

Smoldering is the slow, low-temperature, flameless form of combustion, sustained by the heat evolved when oxygen directly attacks the surface of a condensed-phase fuel. It is a typically incomplete combustion reaction. Solid materials that can sustain a smoldering reaction include coal, cellulose, wood, cotton, tobacco, peat, duff, humus, synthetic foams, charring polymers including polyurethane foam, and dust. Common examples of smoldering phenomena are the initiation of residential fires on upholstered furniture by weak heat sources (e.g., a cigarette, a short-circuited wire), and the persistent combustion of biomass behind the flaming front of wildfires (Dean.E. Painter, 1974).

Rapid combustion

Rapid combustion is a form of combustion in which large amounts of heat and light energy are released, which often results in a fire. This is used in a form of machinery such as internal combustion engines and in thermobaric weapons. Sometimes, a large volume of gas is liberated in combustion besides the production of heat and light. The sudden evolution of large quantities of gas creates excessive pressure that produces a loud noise. Such combustion is known as an explosion. Combustion need not involve oxygen; e.g., hydrogen burns in chlorine to form hydrogen chloride with the liberation of heat and light characteristic of combustion (Dean.E. Painter, 1974).

Turbulent combustion

Combustion resulting in a turbulent flame is the most used for industrial application (e.g. gas turbines, gasoline engines, etc.) because the turbulence helps the mixing process between the fuel and oxidizer (Dean.E. Painter, 1974).

Microgravity combustion

Combustion processes behave differently in a microgravity environment than in Earth-gravity conditions due to the lack of buoyancy. For example, a candle's flame takes the shape of a sphere. Microgravity combustion research contributes to understanding of spacecraft fire safety and diverse aspects of combustion physics (Dean.E.Painter, 1974).

Slow combustion

Slow combustion is a form of combustion which takes place at low temperatures. Cellular respiration is an example of slow combustion (Dean.E.Painter, 1974).

1.2 Problem Statement

Air pollution is now becoming a household name even in developing countries like Zambia. Therefore, as Zambia strives to achieve the 2030 vision of being a middle income country, a balance between fossil energy use and emissions produced must be met. This is so, because industrial activities have to be increased to bring about more employment hence better lives, which is a middle economy indicator. A price will surely have to be paid for these activities and this will be in the form high levels of air pollution. As this development will be gradual, early monitoring of the pollution levels is highly required. This will help the concerned higher authorities make informed decisions, e.g. in deciding what kind of industries can be set up. The impacts of air pollution such as the ones (e.g. acid rain, unclean air) experienced in developed countries are not that significant in Zambia but this does not mean that they may never be. If the air pollutants are not checked and monitored, Zambia will one day wake up to the surprise of high pollution levels and very disastrous consequences. In these lines, it must be emphasized that this project will endeavor to check the air pollution levels in Lusaka, using appropriate and readily available methods, and then document them.

1.3 Objectives

1.3.1 Main Objectives

1. To investigate the levels of air pollution in Lusaka.
2. To investigate the impact of air pollution in Lusaka..

1.3.2 Specific objectives

1. Identify the number of companies that pollute the air and the levels of pollution they produce.
2. Identify the number of companies that exercise cleaner production.
3. Understand the flow and spread of smoke produced by industries.

1.4 LITERATURE REVIEW

1.4.1 Introduction

Air pollution is not a new phenomenon and is a concern for both developed and developing countries. Lusaka city being a fast growing city in a developing country has a reason to get concerned with its levels of air pollution. Most of the air pollution problems today are as a result of increased industrial activities and transportation. As already mentioned, Zambia is a developing country and thus it is less industrialized. For this particular reason, it is considered to be contributing a negligible amount of air pollutants to the atmosphere on a global basis. Based on this reason, very few research projects have been carried to investigate the levels of air pollution in Lusaka and hence very little literature is available.

1.4.2 Air pollution in SADC region

Like other sub- Saharan African countries, a striking feature of the energy sector in SADC is the substantial reliance on traditional biomass energy- wood, charcoal, corn cobs, cotton stalks and animal dung cakes. Biomass energy, on average, accounts for over 70% of the total energy supply in the SADC region, proportions which may vary from over 90% in Tanzania to under 50% in Zimbabwe. Nevertheless, imported petroleum products still account for between 20% to 40% of national export revenue. This energy mix means that net carbon emissions from SADC countries remain very low. Per capita carbon emissions in the SADC countries have been estimated to be below one tonne per capita per annum, compared to a global average of 1.2 tonnes (Subak et'al, 1993). The contribution of SADC to total global emissions is less than 2% for all greenhouse gases and, with the exception of the carbon emissions from land biota, South Africa emits vastly more carbon than the rest of the SADC region combined (table 1.2).

Table 1.2- showing the emissions of carbon, N_2O and CFC per country of the SADC region

Country	Total (per capita (T))	C emissions (MT)		N_2O (MT)	CFC-H Equiv. (KJ)
		Energy	Biota		
Angola	1.4	2.0	12.4	3	1
Botswana	0.9	0.7	0.5	0	0
Lesotho	n/a	0.1	n/a	0	0
Malawi	0.5	0.3	5.2	2	1
Mozambique	0.5	0.5	6.5	2	1
Namibia	0.9	0.7	0.7	0	0
Swaziland	1.7	69	-1.1	22	14
Tanzania	-0.6	0.2	-0.7	0	0
Zambia	0.2	0.5	6.4	3	2
Zimbabwe	1.4	0.8	11.2	3	1
South Africa	0.6	3.7	2.3	2	1
SADC	1.0	78.4	43.3	37	21
Global	1.2	6431.9	855.9	3783	1369
SADC as % of global	82%	1.2%	5.1%	1.0%	1.5%

Source: Air pollution issues in Southern Africa

Net carbon emissions from land use in the region are higher than from energy, however, and SADC contributes about 5% to global carbon emissions originating from land biota.

The factors that are going to have the greatest influence on future energy consumption in SADC are population and urbanization growth, economic and industrial growth and improvements in the efficiency of energy use and the advent of new and improved energy technologies. Population in the region is projected to rise from 136 million to nearly 300 million by 2025 (SARDC, 1994), despite a fall in the annual growth rate from about 3% to just over 2%. Currently, the household sector accounts for about 60% of energy consumption in the region and energy consumption per capita has been rising during the 1980s at between one and five percent per annum, with a regional average of about 2%. Combining the projected increase in population with a continuation of the per capita demand for more energy, leads to at least a ten-fold increase in demand for energy by the 2050s (Apina, 1998).

1.4.3 Air pollution study in Zambia.

1.4.3.1 Measurements in Lusaka.

Some efforts have been made to assess the levels of air pollutants in Zambia. One such effort was made by two Swedish nationals by the names of Christine Guerreiro and Bfarne Sovertsen. They managed to measure the levels of SO_2 and NO_2 at two sites in Lusaka city. The sites were the areas around the Norwegian embassy and around the Featex building. The results of their investigation were compiled and documented in a book entitled, ''Passive Sampling of SO_2 and NO_2 ambient air concentrations in Zambia (September 1998)''. The tabulated results of the two sites are shown in table 4.2;

Table 1.3- Passive samplers data

City	Site Name (position)	Area	Emission source	Position to emission source	UTM coordinates		Passive Samplers		Period (days)
Lusaka	Embassy of Norway	City Background			640,3	295,3	1	1	11.13
Lusaka	Featex Building	City Centre	Traffic	20 m west	637,3	295,6	1	1	7.24

Source: Passive Sampling of SO_2 and NO_2 ambient air concentrations in Zambia

Table 1.4-Measured concentrations

	$SO_2(\mu g/m^3)$	$NO_2(\mu g/m^3)$
Norway	2	7
Featex	4	14

Table 1.5-Air quality guidelines for SO_2 and NO_2

		24 hour average	
Component	Effect	SFT	WHO
SO_2	Health Vegetation	90($\mu g/m^3$) 50($\mu g/m^3$)	125($\mu g/m^3$)
NO_2	Health	75($\mu g/m^3$)	150($\mu g/m^3$)

Source: 'Passive Sampling of SO_2 and NO_2 ambient air concentrations in Zambia

The methods used to collect the results outlined above shall be thoroughly studied and if relevant shall be used in the current project.

1.4.3.2 Air quality mapping in Kitwe area of the Copperbelt.

An air quality mapping campaign using diffusive samplers for SO_2 and NO_2 was undertaken in the Kitwe area in October to November 2002(Sjoberg et'al.2003). The air quality mapping campaign included ambient, indoor and personal monitoring. The outcomes of the ambient monitoring indicated high levels of SO_2. The SO_2 concentrations, measured as 2- week means, within the smelter plant area were well in excess of the WHO and Zambia 24 hr guideline value (125 $\mu g/m^3$). The workers at the smelter plants were exposed to SO_2 concentrations greater than 2000 $\mu g/m^3$ as a mean value during a 40 hrs working week, which is well above the WHO and Zambian guideline value as a 10 min mean value of 500 $\mu g/m^3$. Concentrations of NO_2 in mainly, below 15 $\mu g/m^3$ were found to be well within the WHO annual mean guideline of 40 $\mu g/m^3$. It is therefore likely that people living in Kitwe and those working in the copper smelter experience associated health effects. At concentrations (> 250 $\mu g/m^3$) reported in the air quality mapping campaign, health effects likely to occur include exacerbation of respiratory symptoms, and cardiovascular and respiratory mortality (WHO, 2000).

1.4.4 Health impacts of air pollution

Since the onset of the industrial revolution, there has been a steady change in the composition of the atmosphere mainly due to the combustion of fossil fuels used for the generation of energy and transportation.

Air pollution is a major environmental health problem affecting the developing and the developed countries alike. The effects of air pollution on health are very complex as there are many different sources and their individual effects vary from one to the other. It is not only the ambient air quality in the cities but also the indoor air quality in the rural and the urban areas that are causing concern. In fact in the developing world the highest air pollution exposures occur in the indoor environment. Air pollutants that are inhaled have serious impact on human health affecting the lungs and the respiratory system; they are also taken up by the blood and pumped all round the body. These pollutants are also deposited on soil, plants, and in the water, further contributing to human exposure.

The level of risk depends on several factors;

- The amount of pollution in the air.
- The amount of air we breathe in a given time.
- Our overall health

Other less direct ways people are exposed to air pollutants are;

- Eating food products contaminated by air toxins that have been deposited where they grow.
- Drinking water contaminated by air pollutants.
- Ingesting contaminated food and touching contaminated soil, dust or water.

1.4.5 Sources of air pollution

Air pollutants consist of gaseous pollutants, odours, and SPM, (suspended particulate matter) such as dust, fumes, mist, and smoke. The concentration of these in and near the urban areas causes severe pollution to the surroundings. The largest sources of human-created air pollution are energy generation, transportation, and industries that use a great deal of energy sources. Depending on their source and interactions with other components of the air, they can have different chemical compositions and health impacts. Since these pollutants are generally concentrated in and around urban areas, the outdoor urban pollution levels are far higher than in the rural areas.

Fires are another major source of air pollution and can lead to severe problems if the smoke is inhaled for a period of time. These fires can either be forest fires, oil well fires, burning of leaves in the backyard or as in the case of rural areas, large-scale burning of agricultural waste. Other sources include industries and power plants located in these areas.

The main sources of air pollution in Zambia are;

- Stationary/point sources- Smelters, acid plants, driers, kilns and boilers in the mines and industries.
- Mobile/Line sources- Automobiles, motor bikes and trains.
- Area sources- Coal mines, rock and sand quarries, fuel stations, biomass burning and agriculture.

Table 1.6-Common atmospheric pollution sources and their pollutants

Category	Source	Emitting pollutants
Agriculture	Open burning	Suspended particulate matter, carbon monoxide, volatile organic compounds
Mining and quarrying	Coal mining; crude oil and gas production; stone quarrying	Suspended particulate matter, sulphur dioxide, oxides of nitrogen, volatile organic compounds
Power generation	Electricity; gas; steam	Suspended particulate matter, sulphur dioxide, oxides of nitrogen, carbon monoxide, volatile organic compounds, sulphur trioxide, lead
Transport	Combustion engines	Suspended particulate matter, sulphur dioxide, oxides of nitrogen, carbon monoxide, volatile organic compounds, lead
Community service	Municipal incinerators	Suspended particulate matter, sulphur dioxide, oxides of nitrogen, carbon monoxide, volatile organic compounds, lead

Table 7 Source: http//edugreen.teri.res.in/health.html

1.4.6 Impact of air pollution on health

The magnitude of the London fog of 1952, which affected such a large number of people, was the first incident that made people aware of the damage done to the atmosphere due to industrialization. The SPM levels increased manifold and resulted in over 4000 deaths.

Indoor air pollution can be particularly hazardous to health as it is released in close proximity to people. It is stated that a pollutant released indoors is many times more likely to reach the lung than that released outdoors. In the developing countries a fairly large portion of the population is dependent on biomass for their energy requirements. These include wood, charcoal, agricultural residue, and animal waste. Open fires used for cooking and heating are commonly found in the household both in the rural and the urban areas. The stove is often at floor level, adding to the risk of accident and the hygiene factor. In addition, they are often not fitted with a chimney to remove the pollutants. In such households the children and women are most likely to be affected, as they are the group that spends more time indoors. The main pollutant in this environment is the SPM. In fact, deaths due to indoor air pollution, mainly particulate matters, in the rural areas of India are one of the highest in the world. Many of the deaths are due to acute respiratory infections in children; others are due to cardiovascular diseases, lung cancer, and chronic respiratory diseases in adults. If emissions are high and ventilation is poor, household use of coal and biomass can severely affect the indoor air quality.

Pollutant emissions per meal are also very high compared to those of other fuels. Household use of fossil fuel is also fairly common in the developing countries, particularly coal—both bituminous and lignite. These are particularly damaging as they burn inefficiently and emit considerable quantities of air pollutants. If emissions are high and ventilation poor, then the exposure levels to the gases emitted are far higher. The most harmful of the gases and agents that are emitted are particulate matter, carbon dioxide, polycyclic organic matter, and formaldehyde. The indoor concentrations of these gases are far much higher than the acceptable levels, and is cause for concern in rural areas.

1.4.6.1 Health impact of specific air pollutants

Some of these gases can seriously and adversely affect the health of the population and should be given due attention by the concerned authority. The gases mentioned below are mainly outdoor air pollutants but some of them can and do occur indoor depending on the source and the circumstances.

Tobacco smoke. Tobacco smoke generates a wide range of harmful chemicals and is a major cause of ill health, as it is known to cause cancer, not only to the smoker but affecting passive smokers too. It is well-known that smoking affects the passive smoker (the person who is in the vicinity of a smoker and is not himself/herself a smoker) ranging from burning sensation in the eyes or nose, and throat irritation, to cancer, bronchitis, severe asthma, and a decrease in lung function.

- Biological pollutants. These are mostly allergens that can cause asthma, hay fever, and other diseases
- Volatile organic compounds. Volatile compounds can cause irritation of the eye, nose and throat. In severe cases there may be headaches, nausea, and loss of coordination. In the longer run, some of them are suspected to cause damage to the liver and other parts of the body.
- Formaldehyde. Exposure causes irritation to the eyes, nose and may cause allergies in some people.
- *Lead.* Prolonged exposure can cause damage to the nervous system, digestive problems, and in some cases cause cancer. It is especially hazardous to small children.
- Radon. A radioactive gas that can accumulate inside the house, it originates from the rocks and soil under the house and its level is dominated by the outdoor air and also to some extent the other gases being emitted indoors. Exposure to this gas increases the risk of lung cancer.
- Ozone. Exposure to this gas makes our eyes itch, burn, and water and it has also been associated with increase in respiratory disorders such as asthma. It lowers our resistance to colds and pneumonia.
- Oxides of nitrogen. This gas can make children susceptible to respiratory diseases in the winters.
- Carbon monoxide. CO (carbon monoxide) combines with haemoglobin to lessen the amount of oxygen that enters our blood through our lungs. The binding with other haeme proteins causes

changes in the function of the affected organs such as the brain and the cardiovascular system, and also the developing foetus. It can impair our concentration, slow our reflexes, and make us confused and sleepy.

- Sulphur dioxide. SO_2 (sulphur dioxide) in the air is caused due to the rise in combustion of fossil fuels. It can oxidize and form sulphuric acid mist. SO_2 in the air leads to diseases of the lung and other lung disorders such as wheezing and shortness of breath. Long-term effects are more difficult to ascertain as SO_2 exposure is often combined with that of SPM.
- SPM *(*suspended particulate matter*)*. Suspended matter consists of dust, fumes, mist and smoke. The main chemical component of SPM that is of major concern is lead, others being nickel, arsenic, and those present in diesel exhaust. These particles when breathed in, lodge in our lung tissues and cause lung damage and respiratory problems. The importance of SPM as a major pollutant needs special emphasis as;

a) It affects more people globally than any other pollutant on a continuing basis;

b) There is more monitoring data available on this than any other pollutant;

c) More epidemiological evidence has been collected on the exposure to this than to any other pollutant.

CHAPTER TWO

Methodology

2.0 Introduction

1. In order to investigate the levels of air pollution in Lusaka city, a number of sources have to be first identified.
2. The main sources are the industries located within the city.
3. The exact positions of these industries will be marked and a map produced.
4. The industries identified will be put into different categories and analyzed differently.
5. The different categories will be according to the kind of fuel the industry uses for combustion. Only three types of fuels can be used for combustion and these are liquid, gas and solid fuels.

Two approaches will be followed in order to make this project a success. Firstly, it is important to understand that both approaches are based on the analysis of the smoke produced by the industries. The approaches are explained below;

i. The first approach will involve the actual identification of the gases contained in the smoke produced. Some of the major gases that will be under investigation are carbon dioxide (CO_2), carbon monoxide (CO) and sulphur dioxide (SO_2). In this approach, different appropriate apparatus will be identified and used in the actual gas measurements.

ii. The second approach involves understanding the flow of the smoke in the atmosphere. PHOENICS acronym for Parabolic Hyperbolic or Elliptic Numeric Integration Code Series will be used. PHOENICS is a general-purpose software package which predicts quantitatively:-

- how fluids (air, water, steam, oil, blood, etc) flow in and around:
  - engines,
  - process equipment,
  - buildings,
  - human beings,
  - lakes, river and oceans,
  - and so on;
- the associated changes of chemical and physical composition;

- the associated stresses in the immersed solids

In this particular project PHOENICS will be used to predict the flow of the smoke produced from the chimneys of each and every industry in concern. Of course some data has to be entered to help the software carry out the aforementioned task. Variables such as the temperature, velocity and pressure will have to be obtained from the site and entered in the software. The result showing the extent of the spread and the concentration will be manipulated and produced by the software.

Using the first mentioned approach, various emission estimating techniques have been identified for use in this project. The four emission estimation techniques are outlined below;

2.1 Emission estimation techniques

- Sampling or direct measurement
- Mass balance
- Fuel analysis or other engineering calculations
- Emission factors

The above mentioned techniques are clearly explained below;

2.1.1 Sampling or direct measurement

Once the composition of the smoke sample is known and understood, the actual concentrations of the constituents are measured by the appropriate apparatus. A smoke emanating from combustion of a fuel containing carbon will obviously contain carbon dioxide (CO_2) and maybe carbon monoxide (CO) depending upon whether the combustion is complete or not.

There are two kinds of air pollution measurements: ambient measurements (concentration of pollutants in the air the public breathes, or ambient monitoring) and source measurements (concentrations and/or emission rates from air pollution sources, or source testing). Concentrations in the ambient air must be measured to determine whether that air is indeed safe to breathe (i.e., it meets the ECZ standards). To control pollutant concentrations, we must regulate the time, place, and amount of their emissions. Thus emission rates of various sources of air pollutants (e.g., factories, power plants, automobiles) must be measured.

2.1.1.1 A representative sample

Any air pollution measurement involves two problems. The first is to obtain a suitable, representative sample; the second is to determine the concentration of the pollutant of interest in it correctly. Generally the first is harder.

What constitutes a representative ambient air sample has been the topic of prolonged legal and technical controversy. The air inside the parking structure normally contains much more CO than the ECZ allows for ambient air. So if one takes a sample directly across the street from such a structure, in most cases the concentration will be an order magnitude less than inside the structure. A block way, the concentration will be even less. On the sidewalk directly adjacent to the structure the concentration will be perhaps twice as high as on opposite side of the street. Which, if any, of these locations is suitable for obtaining a sample of ambient air? Generally the ambient air sampler should be located at the place to which the public has free access where the pollutant concentration is highest. This excludes all indoor spaces and plant sites to which the public has no access. Table 2.6 shows the ECZ guideline limits for some pollutants.

Table 2.6 - Plant source emission guidelines

Parameter	Reference Time	Guideline Limit
SO_2	10 min	500 ($\mu g/m^3$)
	1 hour	350 ($\mu g/m^3$)
NO_x as NO_2	1 hour	400 ($\mu g/m^3$)
	24 hours	150 ($\mu g/m^3$)
CO	15 min	100 mg/m^3
	30 min	60 mg/m^3
	1 hour	30 mg/m^3
	8 hours	10 mg/m^3

Source: www.necz.org

An ambient monitor must be placed where it has power, shelter from rain and snow, perhaps a constant temperature environment, easy access for monitoring personnel, protection from vandalism.

In source testing, the representative sample problem is equally difficult. Gas flow in a large industrial flue or smokestack may be steady and well mixed across the diameter of the stack, in which case any sample taken any time and any place in the stack will be representative. But for most such stacks the velocity and the concentration in the stack vary from point to point and from time to time, so that separate measurements must be made and averaged. A description of a gas stack is given below;

2.1.1.2 Flue gas stack

A **flue gas stack** is a type of chimney, a vertical pipe, channel or similar structure through which combustion product gases called flue gases are exhausted to the outside air. Flue gases are produced when coal, oil, natural gas, wood or any other fuel is combusted in an industrial furnace, a power plant's steam-generating boiler, or other large combustion device. Flue gas is usually composed of carbon dioxide (CO_2) and water vapor as well as nitrogen and excess oxygen remaining from the intake combustion air. It also contains a small percentage of pollutants such as particulate matter, carbon monoxide, nitrogen oxides and sulfur oxides. The flue gas stacks are often quite tall, up to 400 meters (1300 feet) or more, so as to disperse the exhaust pollutants over a greater area and thereby reduce the concentration of the pollutants to the levels required by governmental environmental policy and environmental regulation.

When the flue gases are exhausted from stoves, ovens, fireplaces, or other small sources within residential abodes, restaurants, hotels, or other public buildings and small commercial enterprises, their flue gas stacks are referred to as chimneys.

Flue gas stack draft (or draught)

The combustion flue gases inside the flue gas stacks are much hotter than the ambient outside air and therefore less dense than the ambient air. That causes the bottom of the vertical column of hot flue gas to have a lower pressure than the pressure at the bottom of a corresponding column of outside air. That higher pressure outside the chimney is the driving force that moves the required combustion air into the combustion zone and also moves the flue gas up and out of the chimney. That movement or flow of combustion air and flue gas is called "natural draft (or draught)", "natural ventilation", "chimney effect", or "stack effect". The taller the stack, the more draft (or draught) is created.

The equation below provides an approximation of the pressure difference, ΔP, (between the bottom and the top of the flue gas stack) that is created by the draft:

$$\Delta P = C\, a\, h \left(\frac{1}{T_o} - \frac{1}{T_i}\right)$$

where:

ΔP	= available pressure difference, in Pa
C	= 0.0342
a	= atmospheric pressure, in Pa
h	= height of the flue gas stack, in m
T_o	= absolute outside air temperature, in K
T_i	= absolute average temperature of the flue gas inside the stack, in K

The above equation is an approximation because it assumes that the molar mass of the flue gas and the outside air are equal and that the pressure drop through the flue gas stack is quite small. Both assumptions are fairly good but not exactly accurate.

The flue gas flow rate induced by the draft

As a "first guess" approximation, the following equation can be used to estimate the flue gas flow rate induced by the draft of a flue gas stack. The equation assumes that the molar mass of the flue gas and the outside air are equal and that the frictional resistance and heat losses are negligible:

$$Q = C\,A\,\sqrt{2\,g\,H\,\frac{T_i - T_o}{T_i}} \qquad \text{Eqn 1.6}$$

where:

Q = flue gas flow rate, m^3/s

A = cross-sectional area of chimney, m^2 (assuming it has a constant cross-section)

C = discharge coefficient (usually taken to be from 0.65 to 0.70)

g = gravitational acceleration at sea level, 9.807 m/s^2

H = height of chimney, m

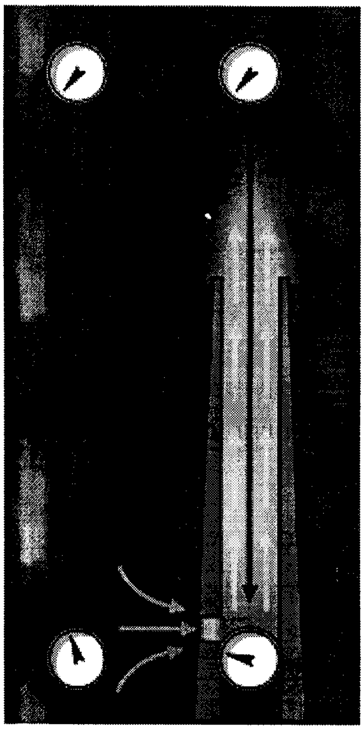
T_i = absolute average temperature of the flue gas in the stack, K

T_o = absolute outside air temperature, K

Designing chimneys and stacks to provide the correct amount of natural draft involves a great many factors such as:

- The height and diameter of the stack.
- The desired amount of excess combustion air needed to assure complete combustion.
- The temperature of the flue gases leaving the combustion zone.
- The composition of the combustion flue gas, which determines the flue gas density.
- The frictional resistance to the flow of the flue gases through the chimney or stack, which will vary with the materials used to construct the chimney or stack.
- The heat loss from the flue gases as they flow through the chimney or stack.
- The local atmospheric pressure of the ambient air, which is determined by the local elevation above sea level.

The calculation of many of the above design factors requires trial-and-error reiterative methods.



The stack effect in chimneys: the gauges represent absolute air pressure and the airflow is indicated with light grey arrows. The gauge dials move clockwise with increasing pressure.

2.1.2 Mass Conservation (Continuity)

In case of the mass balance for the fluid element: Rate of increase of mass in fluid element is equal to net rate of flow of mass into the fluid element. The rate of increase of mass in the fluid element is:

$$\frac{\partial}{\partial t}(\rho\rho\ \delta x\ \delta y\ \delta z) = \frac{\partial \rho\rho}{\partial t}\delta x\ \delta y\ \delta z$$

The mass flow rate across a face of the element is given by product of density, area and the

$$\left(\rho u - \frac{\partial(\rho u)}{\partial x}.\frac{1}{2}\delta x\right)\delta y\, \delta z - \left(\rho u + \frac{\partial(\rho u)}{\partial x}.\frac{1}{2}\delta x\right)\delta y\, \delta z$$
$$+\left(\rho v - \frac{\partial(\rho v)}{\partial y}.\frac{1}{2}\delta y\right)\delta x\, \delta z - \left(\rho v + \frac{\partial(\rho v)}{\partial y}.\frac{1}{2}\delta y\right)\delta x\, \delta z$$
$$+\left(\rho w - \frac{\partial(\rho w)}{\partial z}.\frac{1}{2}\delta z\right)\delta x\, \delta y - \left(\rho w + \frac{\partial(\rho w)}{\partial z}.\frac{1}{2}\delta z\right)\delta x\, \delta y \qquad \text{Eq.2.2}$$

velocity component normal to the face. From Fig.2.2 the net rate of flow of mass into the element across its boundaries is given by:

Flows into the element produce an increase of mass in the element and have a positive sign, while flows out of the element have a negative sign.

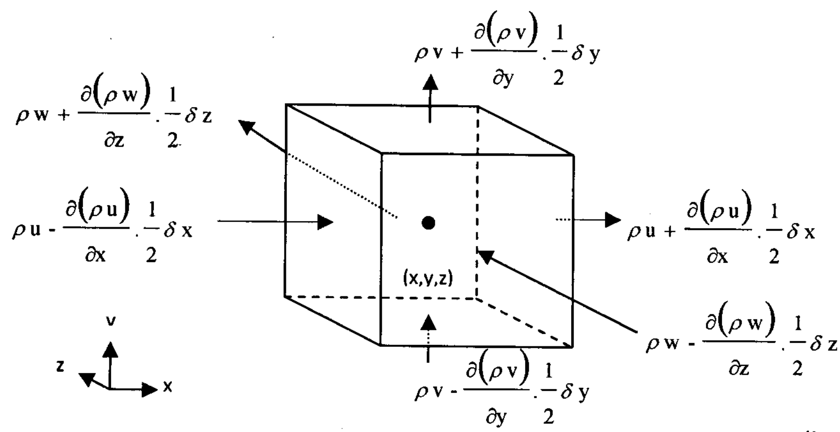


Figure 2.2 Mass flow in and out of a fluid element.

The rate of increase of mass inside the element, Eq.2.1, is equated to the net rate of flow of mass into the element across its faces, Eq.2.2. The expression is divided by the elemental volume (δx δy δz) throughout.

All terms of the resulting mass balance are arranged on the left hand side of the equation giving:

$$\frac{\partial \rho}{\partial t} + \frac{\partial(\rho u)}{\partial x} + \frac{\partial(\rho v)}{\partial y} + \frac{\partial(\rho w)}{\partial z} = 0 \qquad \text{Eq1.7}$$

In a more compact vector notation:

Equation 2.4 is the unsteady, three-dimensional mass conservation or continuity equation at a

$$\frac{\partial \rho}{\partial t} + \operatorname{div}(\rho \mathbf{u}) = 0 \qquad \text{Eq. 1.8}$$

point in a compressible fluid. The first term on the left hand side is the rate of change in time of density (mass per unit volume). The second term describes the net flow of mass out of the element across its boundaries, and is known as the convective term.

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} = 0 \qquad \text{Eq.1.9}$$

For an incompressible fluid (i.e. a liquid) the density ρ is constant and Eq.2.3 in longhand notation becomes:

Using Eq.1.8 for an incompressible fluid Eq.1.9 can be expressed as:

$$\operatorname{div}(\mathbf{u}) = 0$$

Eqn 1.10

2.1.3 Fuel analysis or other engineering calculations

Here, equations relating the reactants of combustion to the product are employed. It is possible to determine an estimate amount of a pollutant gas produced from a given amount of fuel combusted. For instance, carbon dioxide emissions could be determined from the following equations;

Generally, the chemical equation for stoichiometric burning of hydrocarbon in oxygen is

$$C_xH_y + \left(x + \frac{y}{4}\right) O_2 \rightarrow xCO_2 + \left(\frac{y}{2}\right) H_2O$$

Eqn 1.11

For example, the burning of propane is

$$C_3H_8 + 5O_2 \rightarrow 3CO_2 + 4H_2O$$ Eqn 1.12

Generally, the chemical equation for stoichiometric incomplete combustion of hydrocarbon in oxygen is as follows:

$$(z)\,C_xH_y + \left(z\left(\frac{x}{2} + \frac{y}{4}\right)\right)O_2 \rightarrow z \cdot xCO + \left(\frac{z \cdot y}{2}\right)H_2O$$ Eqn 1,13

For example, the incomplete combustion of propane is:

$$2C_3H_8 + 7O_2 \rightarrow 2C + 2CO + 8H_2O + 2CO_2$$ Eqn 1.14

The simple word equation for the combustion of a hydrocarbon in oxygen is:

$$\text{Fuel} + \text{Oxygen} \rightarrow \text{Heat} + \text{Water} + \text{Carbon dioxide}$$ Eqn 1.15

If the combustion takes place using air as the oxygen source, the nitrogen can be added to the equation, as and although it does not react, to show the composition of the flue gas:

$$C_xH_y + \left(x + \frac{y}{4}\right)O_2 + 3.76\left(x + \frac{y}{4}\right)N_2 \rightarrow xCO_2 + \left(\frac{y}{2}\right)H_2O + 3.76\left(x + \frac{y}{4}\right)N$$

Eqn 1.16

For example, the burning of propane is:

$$C_3H_8 + 5O_2 + 18.8N_2 \rightarrow 3CO_2 + 4H_2O + 18.8N_2$$ Eqn 1.17

The simple word equation for the combustion of a hydrocarbon in air is:

$$\text{Fuel} + \text{Air} \rightarrow \text{Heat} + \text{Water} + \text{Carbon dioxide} + \text{Nitrogen}$$ Eqn 1.18

2.1.4 Emission factors

Emission **intensity** is the average emission rate of a given pollutant from a given source relative to the intensity of a specific activity; for example kilograms of carbon dioxide released per mega joule of energy produced, or the ratio of greenhouse gas emissions produced to GDP. Emission intensities are used to derive estimates of air pollutant or green house emissions based on the amount of fuel combusted, the number of animals in animal husbandry, on industrial production levels, distances traveled or similar activity data. Emission intensities may also be used to compare the environmental impact of different fuels or activities. The related terms **emission factor** and **carbon intensity** are often used interchangeably, but "factors" exclude aggregate activities such as GDP, and "carbon" excludes other pollutants.

Table 2.7-Carbon Dioxide Emission Factors for Transportation Fuels[1]

Transportation Fuel	Emission Factors: Kilograms CO_2 Per Unit of Volume per litre	Emission Factors: Kilograms CO_2 Per Million joules
Aviation Gasoline	18.33	69.19
Biodiesel		
-B100	0	0
-B20	17.89	59.44
-B10	20.13	66.35
-B5	21.25	69.76
-B2	21.92	71.8
Diesel Fuel (No. 1 and No. 2)	22.37	73.15
Ethanol/Ethanol Blends		
-E100	0	0
-E85	2.93	14.71
-E10 (Gasohol)	17.59	65.94
Methanol/Methanol Blends		
-M85	10.68	64.01
Motor Gasoline	19.54	70.88
Jet Fuel, Kerosene	21.09	70.88
Natural Gas	120.36 per 1000 cubic metres	53.06
Propane	12.67	63.10
Residual Fuel (No. 5 and No. 6 Fuel Oil)	26.00	78.80

Source: EMEP/CORINAIR Emission Inventory Guidebook

Emission factors can be used in the following word equation;

Pollutant = Emission factor*Production activity

Where:

Pollutant = Tonnes

Emission factor= Kg/Tonne of activity

Production activity=Tonnes

2.2 THE COMPUTER CODE USED

The SIMPLEST algorithm used in this study is embodied in the PHOENICS code. PHOENICS is an acronym for Parabolic Hyperbolic Or Elliptic Numerical Integration Code Series. The PHOENICS computer code was developed by Spalding, D. B. and Rosten, H. I. It is software version 1.4, Document Revision 04 code. Table 2.8 summarises the most important features of PHOENICS. Figure 3.5 shows the block diagram of PHOENICS highlighting its structure.

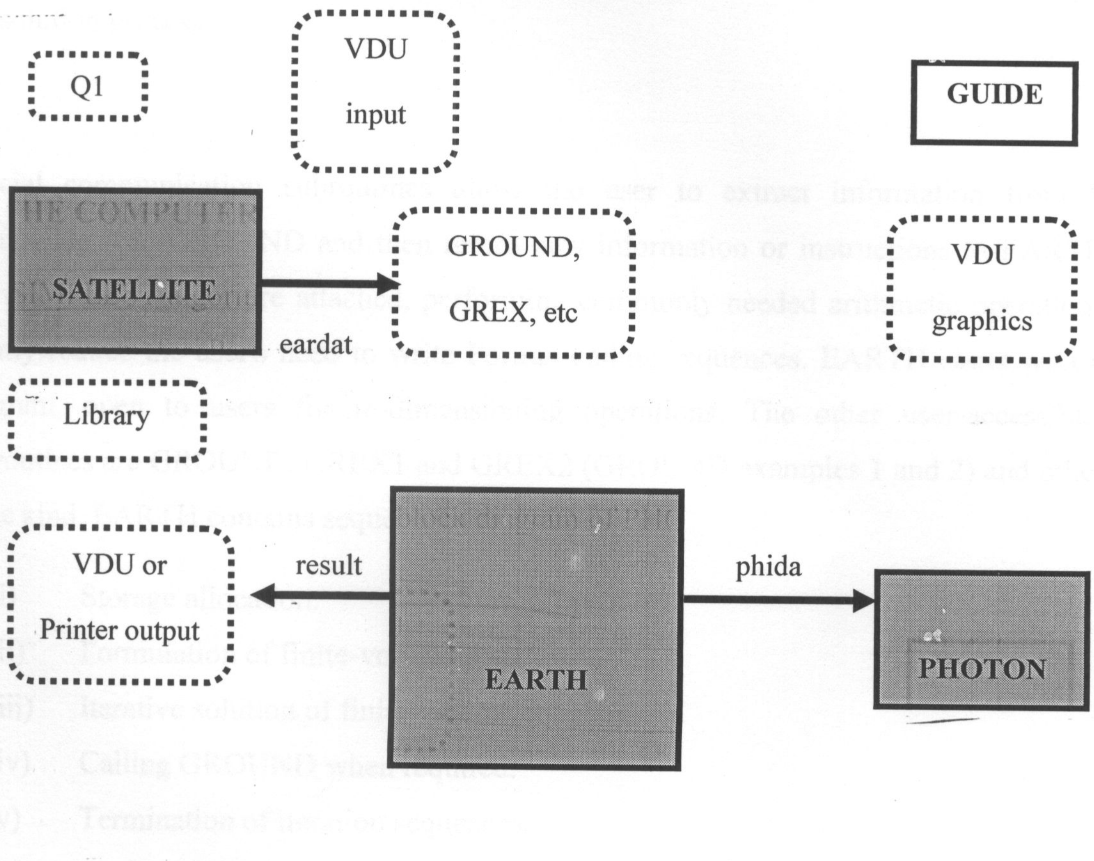


Figure 2.2 Structure of PHOENICS

PHOENICS has a 'planetary' arrangement, with a central core of subroutines called EARTH, and a satellite program, accepting inputs, which correspond to a particular flow simulation. EARTH and the satellite are distinct programs. The satellite is a data-preparation program; it writes a data file which EARTH reads. PHOENICS users work mainly with the satellite, but they can access EARTH also in controlled ways.

GROUND is the EARTH subroutine which users access when incorporating special features of their own. The satellite reads a pre-existing "quick-input file", which may be drawn from a library containing hundreds of examples. The user can then modify the data interactively via the VDU keyboard. A Fortran sub-routine, SATLIT, also accepts user's inputs if these are supplied. A MAIN program is accessible for rarely needed operations, e.g. re-dimensioning. GROUND is a subroutine which is called by EARTH at pre-set points of the solution cycle. If the user inserts appropriate FORTRAN statements at the entry points in GROUND, EARTH absorbs these into the solution process.

Special communication subroutines allow the user to extract information from EARTH, manipulate it in GROUND and then return new information or instructions to EARTH. Many "service" sub-routines are attached, performing commonly needed arithmetic operations. These greatly reduce the user's need to write Fortran-coding sequences. EARTH starts with a MAIN program, open to users for re-dimensioning operations. The other user-accessible source subroutines are GROUND, GREX1 and GREX2 (GROUND examples 1 and 2) and others of the same kind. EARTH contains sequences for:

(i) Storage allocation.
(ii) Formulation of finite-volume equations.
(iii) Iterative solution of finite-volume equations.
(iv) Calling GROUND when required.
(v) Termination of iteration sequences.
(vi) Output of results.

The program EARTH of PHOENICS controls and executes the solution procedure as follows:

1. Obtain information about co-ordinate system, domain lengths and variable definitions to solve and establish number of algebraic equations per dependent variable.
2. The coefficients and sources are regarded as temporarily constant so that the linear-equation solver can be used to solve the equation sets.
3. On the next cycle, the coefficients and sources are updated from the latest values of the auxiliary and independent variables, and the linear equations re-assembled and solved.
4. Many sweeps are made in succession, and the process should be continued, ideally, until all equations are in such perfect balance that further adjustments are unnecessary.
5. Output necessary data, iterative or final.

PHOTON is a service routine which allows the picking up of PHIDA file written by EARTH and then, in response to instructions entered by user through VDU keyboard, represents the computed grid and flow pattern graphically on the screen. In EARTH, the coefficients of the discretised equations are calculated and the finite difference equations are solved iteratively employing the SIMPLEST method of Patankar and Spalding [2].

Table 2.8- Summary of Important Features of PHOENICS.

Basic Features	Three-dimension Steady and Unsteady Parabolic, Hyperbolic and Elliptic Solver.
Co-ordinate System	x-y-z Cartesian r-θ Cylindrical-polar z-r Cylindrical BFC (Body Fitted Co-ordinates)
Differencing Scheme	"Fully-Implicit upwind" by default (but user selection of other schemes is available)
Linear Equation Solver	SIMPLEST Alternating direction TDMA with block correction.
Grid	Uniform Non-uniform

CHAPTER THREE

Data collection and Analysis

3.0 Introduction

In accordance with the methods of emission estimation selected, the primary work done in this project was the collection of data from the field and then analysis of the data. The field here refers to the various industries that were indentified and physically visited. As input to the estimation methods, specific data was required and hence collected, such as;

1. Types of boilers/furnaces used
2. Type of fuel used
3. Amounts of fuel used per unit time
4. Operating hours of the boilers/furnaces per day
5. Exhaust gases treatment methods and devices

The Google maps of each industry were also gotten and later used in the PHOENICS software. The maps are in appendix, A.1.
The industries identified for this project are listed and briefly described below;

1) Midlands breweries
2) Zambian breweries
3) Parmalat Zambia
4) Chat breweries
5) National breweries
6) Crescent Holdings
7) Nkwazi breweries
8) Amanita plant
9) Ole plant
10) Chi-Steel company

3.1Collected data as per company

3.1.1 Midlands breweries

Combustion equipment: Boiler

Make: John Thompson Micro pack

Number of boilers: 1

Stack height: 10m

Fuel: coal

Maximum pressure: 7.5 bars

Operating hours: 18hrs-24hrs per day

Fuel used/activity: 0.03Kg/l

Excess air 20%

3.1.2 Chat breweries

Combustion equipment: Boiler

Make: Joseph Adamson and company

Number of boilers: 2

Stack height: 15m

Fuel: Coal

Maximum pressure: 6.0 bars

Operating hours: 20hrs-24hrs per day

Fuel used/activity:

Excess air: 30%

3.1.3 Ole plant

Combustion equipment: Boiler

Stack height: 20m

Make:

Maximum pressure

Operating hours: 18- 24 hrs

Fuel used/activity:

Excess air:

3.1.4 Nkwazi Breweries

Combustion equipment: Boiler

Type of boiler: Cylinder type

Number of boilers: 1

Stack height: 16 metres

Maximum pressure: 250 lbs

Operating hours: 18hrs-24hrs per day

Fuel used/activity:

Excess air:

3.1.5 Chi-Steel company

Combustion equipment: Furnace

Type of furnace: Tilting crucible furnace

Number of furnaces: 3

Stack heights: 20m, 15m and 16m

Fuel: Coal

Operating hours: 8hrs per day

CHAPTER FOUR

Numerical Results and Discussion

4.0 Introduction

This chapter includes both the results from the emission estimation calculations and the simulation. The analysis of the results of simulation forms the last stage of the PHOENICS analysis process. This chapter presents the results of smoke flow, numerical calculations and outlines the specific simulations that were based on the established grid, considered to be sufficiently well refined for the domain. However, the rate of change of the concentration of smoke with distance could not be simulated due to lack of concentration results. The latter simulation results depend on the direct measurement method which was not done hence the failure for the simulation to be done. Nonetheless, the simulation of the pressure and velocity were done and the results presented.

In order to carry out the simulations, it was essential to have a specific environment for simulation by considering a case study. A case study is an already simulated similar problem which is contained in PHOENICS. This case study could be used to develop a new simulation. For the simulation of smoke flow, a control volume was selected which encompassed an identified number of emissions producing industries. The control volume selected here encompassed; Amanita plant, Zambian breweries, Midlands breweries, Chat breweries and Ole plant. The relative positions of the industries are then reflected in PHOENICS including the distances, to scale. However, the industries were represented by flue gas stacks which were differing in height. This control volume is shown in appendix, A.1. Many assumptions have been attached to this control volume, important ones being;

1) The flow of air is one dimensional.
2) The air flows from left to right along the X-axis.
3) The air velocity changes with height and is expressed by the equation; $U = 3(H/10)^{0.28}$ m/s
4) In-between buildings have no effect on the flow of smoke.
5) The initial velocity is equal to 2.5 m/s.
6) The air temperature is assumed to be at $20^{o}C$

Table 4.9- System Parameters of the control volume

Item	**Parameter**	**Description**
1	Height	50m
2	Length	150m
3	Width	40m
4	Inlet and Outlet size	40m×50m
5	Inlet Velocity	2.5m/s
6	Air temperature	23°C
7	Pressure at inlet	101325N/m^2
8	Pressure within	101325N/m^2

All the results of the estimations are shown in table 4.12. Sample calculations of the fuel analysis and emission factor methods using the midlands breweries data are shown below;

Table 4.10- Properties of the coal used

Property	Value
calorific value	17-23MJ/Kg
emission factor	0.37
emission of NO_x	4.5g/Kg
Sulphur content	0.7- 4.0 weight %
Moisture content	2.2-15.9 weight %
Carbon content	44.9-78.2 Weight %
Bulk density	673-913 Kg/m^3
Ash content	3.3-11.7 weight %

4.1 Fuel Analysis Technique

a) $C + O_2 \longrightarrow CO_2$

12 32 44

Mass of C: 78.2% *730 Kg = 571Kg

1 Kg C ⟶ 44/12 Kg CO_2

Therefore,

CO_2: 571*44/12 Kg CO_2

= 2093.7 Kg CO_2

b) S + O_2 ⟶ SO_2

32 32 64

Mass of S: 4% *730 Kg = 29.2Kg

1 Kg S ⟶ 2 Kg SO_2

Therefore,

SO_2: 29.2 * 2 Kg SO_2

= 58.4 Kg

c) Estimation of NOx produced

Table 4.11-Emission of Nitrogen Oxides- NO_x

Fuel	Emission of NO_x(g/Kg fuel)
Oil	3.0
Kerosene	3.0
Coal	4.5
Propane	2.3
Gasoline	2.7
Natural gas	1.0
Butane	2.3
Wood	0.7

Source: www.engineering toolbox.com

NB: Emission depends on application temperatures and air/fuel ratios.

From the Nitrogen contained in the fuel

4.5g/Kg fuel * 730 Kg fuel

= 3.285 Kg

4.2 Emission Factor technique

Table 4.12 - CO_2 emission factors for various fuels

Fuel	Specific Carbon Content (Kg/kg fuel)	Specific Energy Content (Kwh/Kg fuel)	Specific CO_2 emission (Kg co_2/Kwh)
Bituminous Coal	0.75	7.5	0.37
Gasoline	0.9	12.5	0.27
Diesel	0.86	11.8	0.24

Estimation of carbon dioxide produced.

The procedure for the estimation of the CO_2 produced by an activity is as shown below;

CO_2 (Kg) = E.F. * Production Activity

Here,

Production Activity = Energy Consumed

= M*CV

Where;

M = mass of fuel

CV = Calorific Value

Therefore,

Energy = 730Kg * 23MJ/Kg

= 16790MJ

And using the conversion below,

1Kwh ⟶ 3.6 MJ

Energy = 4663.9 Kwh

Therefore,

CO_2 (Kg) = 0.37 Kg CO_2/ Kwh * 4663.9 Kwh

= 1725.6 Kg

Estimation of SO_2 produced.

The procedure for the estimation of the SO_2 produced by an activity is as shown below. The emission factor for SO_2 can be determined from the equation below;

$EF\ SO_2 = 2 * C_{sfuel} * (1-\alpha s) * 10^3$

EF SO_2= emission factor g/Kg

C_{sfuel}= Coal Sulphur Content Kg/Kg

As = Sulphur retention in ash

NB: It is assumed that 95% of the sulphur in coal forms sulphur dioxide (SO_2). Therefore only the results for SO_2 will be calculated and recorded.

Using the same data as for the other pollutants;

$EF\ SO_2 = 2 * C_{sfuel} * (1-\alpha s) * 10^3$

$= 2 * 0.04 Kg/Kg * (1 - 0.2) * 10^{-3}$

$= 0.064 * 10^{-3} g/Kg$

Therefore;

Mass of $SO_2 = 0.064 * 10^{-3} g/Kg * 730\ Kg$

$= 46.72\ Kg$

Table 4.13 – Derived results

COMPANY	TECHNIQUE USED					
	Fuel Analysis			Emission Factors		
	CO_2(Kg)	SO_2 (Kg)	NO_x (Kg)	CO_2 (Kg)	SO_2 (Kg)	NO_x (Kg)
Midlands Breweries	2093.7	58.4	3.285	1725.6	46.72	3.285
Chat Breweries	1857.5	45.7	2.7	1534.4	44	2.134
Zambian Breweries						
Nkwazi Breweries	2185.1	60.4	2.85	1835.71	51.90	2.76
Parmalat Zambia						
Nisco Industry	2289.38	54.6	3.98	2187	49.71	3.81
Chi-Steel	3079	76.21	3.78	2910.86	55.89	3.62

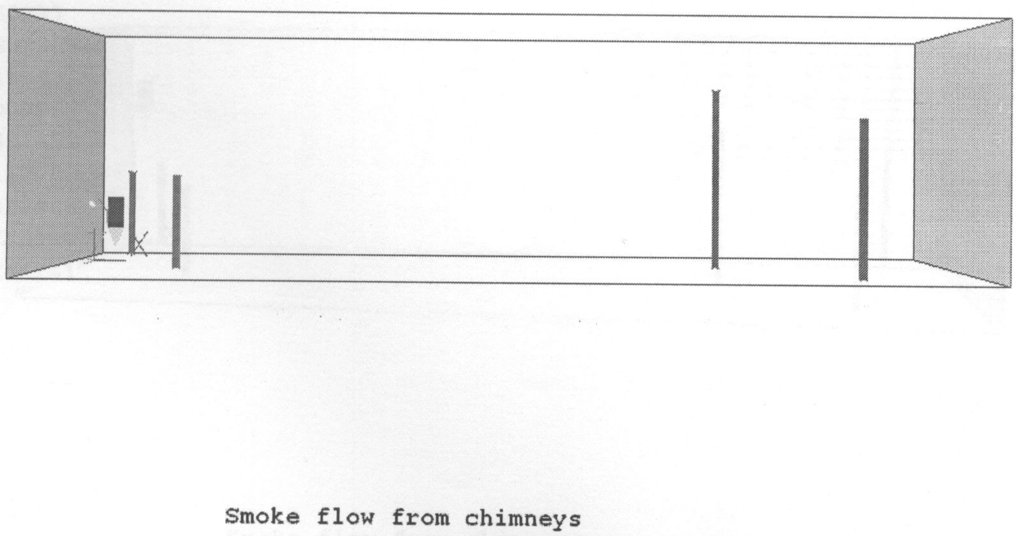


Figure4.3–Control volume

The figure above is a representation of the selected control volume. It encompasses five flue gas stacks each representing the industries shown in appendix, A.2. The smoke produced from these stacks is tracked. Then parameters such as the wind velocity and the pressure are analysed. From the results of the velocity and pressure distribution, it was possible to determine how the smoke produced is carried away and its relation to the environment. In order to easily read the results, graphs of velocity against distance as well as pressure against distance have been plotted. These graphs are discussed later on in this chapter.

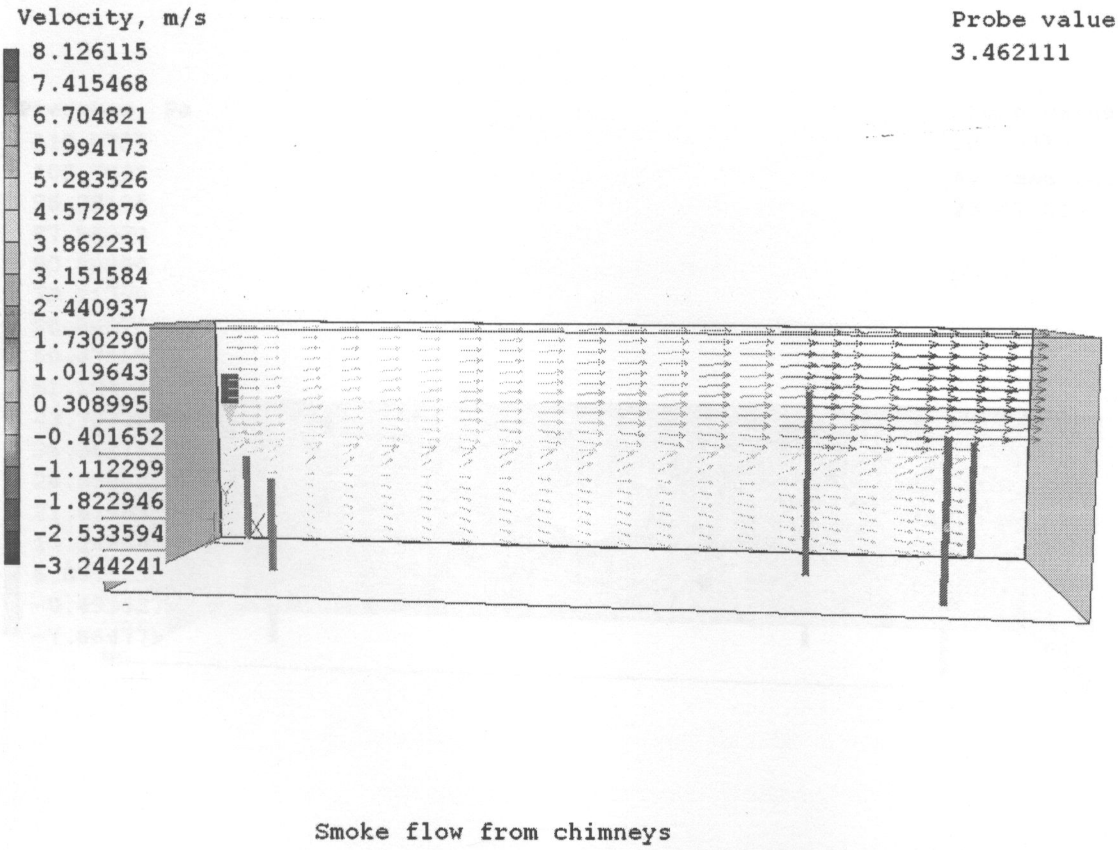


Figure 4.4 – Velocity Vectors

The above figure shows the velocity vectors of the air flowing into the control volume. The velocity arrows clearly indicate the left to right flow. As can be seen from the figure, the arrows are differently colored. From the scale on the left of the figure, the dark colored arrows represent very high velocities in the range of 6 – 8 m/s. The light colored arrows represent medium velocities of 0 – 5.2 m/s, while the color blue represents of lower velocities of negative values, and these are in fact absent from the figure. In the control volume, the red arrows are dominant in the upper end, this simply indicates that the wind velocities are high and any smoke produced by the stacks is carried for a long distance far away. It is also evident that the velocity increases from the inlet to the outlet both with distance and height. However, this may not be so in practice due to obstacles such as buildings and other erected structures. These obstacles may slow down the wind and also concentrate the smoke hence localizing it.

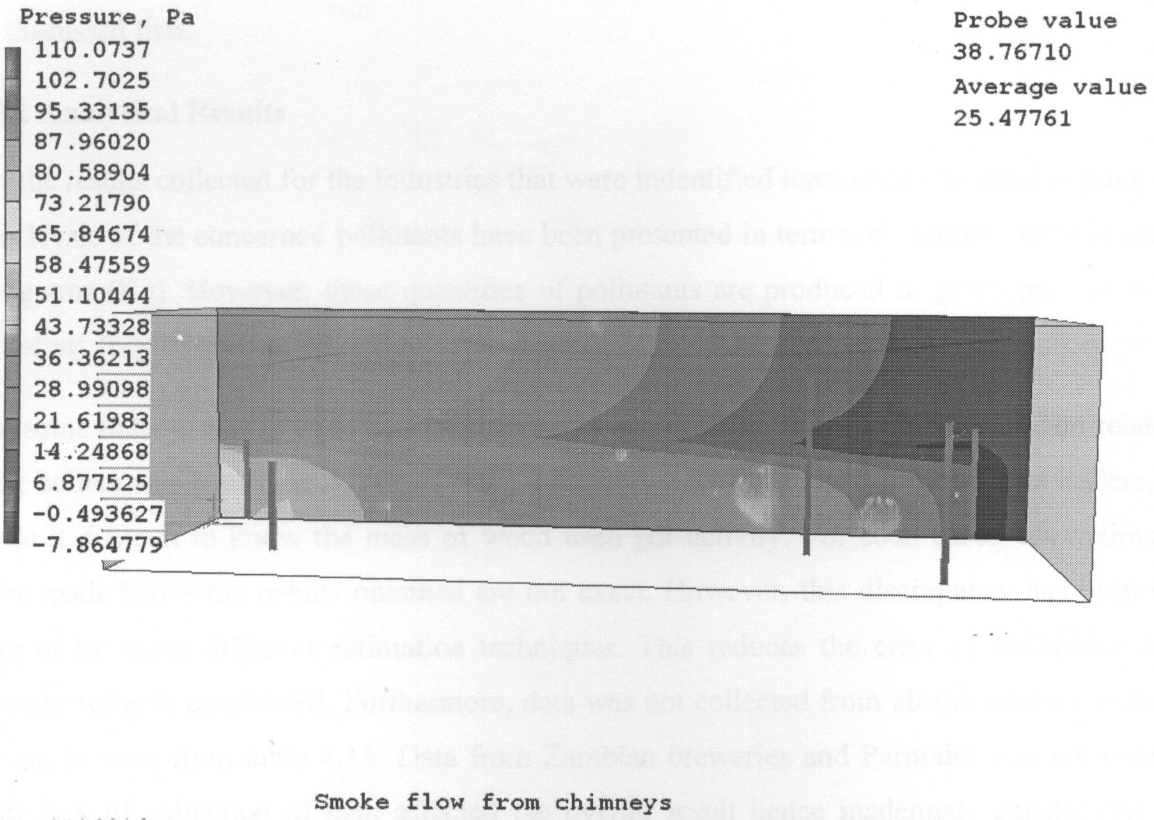


Figure 4.5 – Pressure distribution

The figure above shows the pressure distribution in the control volume. As pressure is a scalar quantity it could not be represented by vector arrows. Hence, only colored regions have been used to distinguish the different pressure regimes. The darkest region towards the end of the control volume represents a region of low pressure, this result is true as high wind velocities cause low pressures. Towards the inlet, a lightly colored region is dominant indicating normal pressures of close to the atmospheric pressure. As was the case with the high velocities, the regions of low pressure have a suctioning effect on the stacks and hence the smoke produced is easily carried away and concentration by localization is prevented.

4.3 Discussion

This chapter presented both the analytical and the simulation results. The analytical results shall be discussed first.

4.3.1 Analytical Results

All the results collected for the industries that were indentified have been tabulated in table 4.10. The levels of the concerned pollutants have been presented in terms of absolute mass in units of kilograms (Kg). However, these quantities of pollutants are produced in given periods of time therefore, they convert to mass flow rates (Kg/h).

For some industries, the analytical calculations were difficult to compute, as the data related to their boilers was insufficient. For instance, chat breweries uses wood on one of its boilers. This made it difficult to know the mass of wood used per activity. For such cases, approximations were made hence the results obtained are not exact. However, this discrepancy has been taken care of by using different estimation techniques. This reduces the error of estimation as the average value is considered. Furthermore, data was not collected from all the selected industries as can be seen from table 4.13. Data from Zambian breweries and Parmalat was not obtained. This lack of collection of data affected the overall result hence inadequate conclusions were drawn.

4.3.2 Simulation Results

As already mentioned, the simulation results are from the analysis of the parameters associated with the flow of smoke in the control volume. These parameters are only the velocity and the pressure. The analysis of these two parameters has been clearly expressed through graphs. Figure 4.11 shows the graph of the velocity against the distance covered.

As can be seen from figure 4.11, the curve increases from a velocity of 3.5 m/s up to a maximum value of 6.5 m/s. At this point, the velocity drops sharply and then gradually to a final value of 4 m/s. This graph could be superimposed on figure 4.12 and could be seen to match with what the vector arrows are indicating.

Also it is clearly seen from figure 4.12 that the curve obtained can be approximated as a straight line. The line has a negative gradient a sign that the pressure reduces with increasing distance.

Also this graph would match with the colored regions indicating the pressure distribution in figure 4.5.

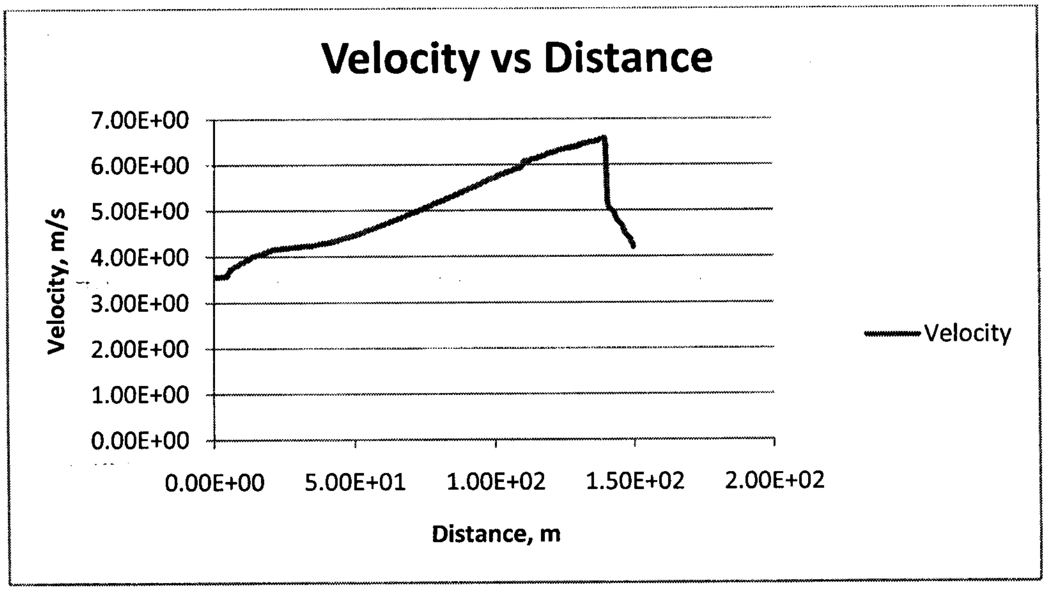


Figure 4.6 - Graph showing relationship between velocity and distance.

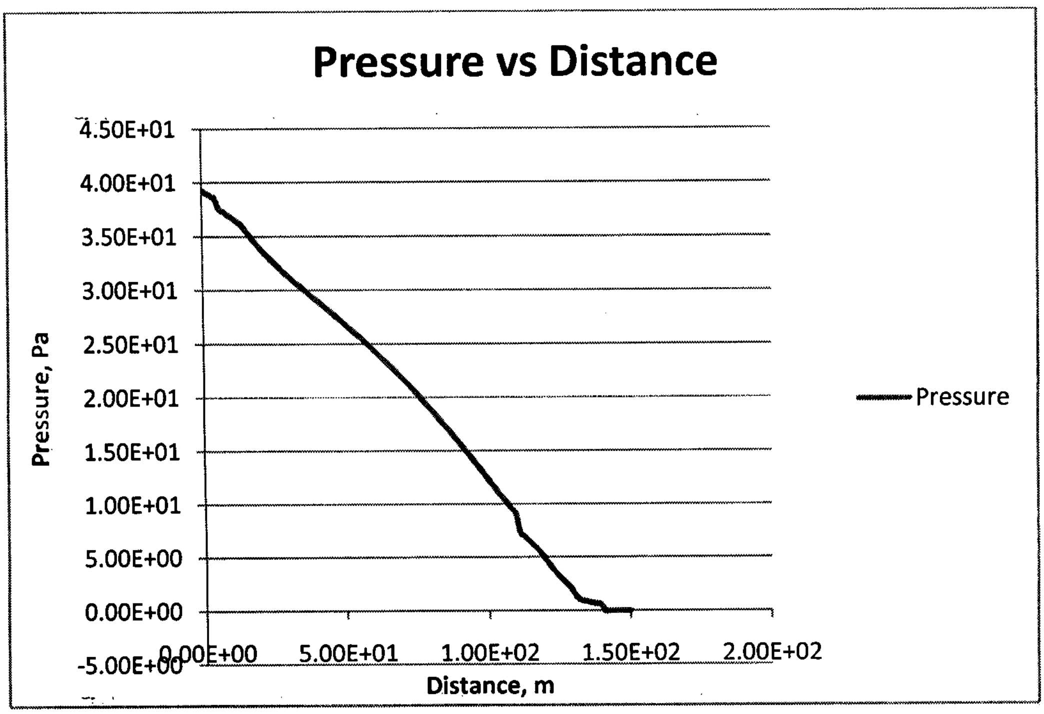


Figure 4.7 – Graph showing relationship between pressure and distance

Chapter Five

Conclusion and Recommendations

5.1 Conclusion

The data collection process in this project was sufficient to meet the specific objectives of the project. The first task was the identification of emission producing industries. This was done by physically visiting the premises, studying their operations, and finally listing all the selected industries. Most of the companies identified used boilers as combustion equipment apart from chi-Steel company which used a tilting furnace. Furthermore, the combustion equipment used by these companies uses coal as fuel. However, chat breweries had improvised to use wood to cut on cost. Google maps were also obtained that clearly showed the relative positions of the industries. These maps made it easy in PHOENICS to track the smoke produced and also study the other parameters associated with it. The levels of pollutants were calculated on a mass basis, i.e. in kilograms. From table 4.13, it can be seen that chi steel company had the highest level of emissions, followed by Nisco industries. Both these companies showed high levels of carbon dioxide.

5.2 Recommendations

Based on the work done in this project, the following recommendations could be made.

- In order to appreciate the results of such work, all available estimation techniques should be used. These techniques include; sampling, fuel analysis, mass conservation and emission factors.
- People managing industries should be sensitized on the importance of reducing emissions. Due to lack of such knowledge, some authorities in some companies offered resistance in the data collection process.
- Zambian industries should understand the benefit of installing pollution abatement devices. Many industries visited did not have any pollution controlling devices, they however relied on making periodic measurements and then rectifying later on. The use of continuous measuring devices could make pollution measurement highly effective.
- Zambian industries should cease to wait on the environmental council of Zambia (ECZ) to measure their flue gases

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APPENDIX

Figure A.1- Map of selected industries