

**AIR POLLUTION MODELLING OF AN INDUSTRIAL
CITY
(A CASE STUDY OF KADUNA INDUSTRIAL AREA)**

BY

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DECLARATION

I hereby declare that this project work was wholly carried out by me, AGADA, DON S.A. under the supervision of DR. ODIGURE, J.O of the Department of Chemical Engineering, Federal University of Technology, Minna, Niger State during the 1998/1999 academic session.

SIGN

DATE

CERTIFICATION

This is to certify that this project titled “Air Pollution Modelling of an Industrial City (Case study of Kaduna Industrial Area)” was carried out by AGADA, DON S.A. under the supervision of DR J.O. ODIGURE and submitted to the Chemical Engineering Department, Federal University of Technology, Minna, in partial fulfilment of the requirements for the award of Bachelor of Engineering (B.Eng) degree in Chemical Engineering.

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DEDICATION

This project work is dedicated to the ever living God and my parents, MR and MRS M.O. AGADA for their unrelentless love and care throughout the duration of my course. My heart and appreciation seriously goes to them.

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In everything you do in life you have to give thanks, so also goes for everything you get in life. There are times when you are overwhelmed with the good things that comes your way and there are also times when things you feel are bad comes your way too. But these things termed "Bad" are usually meant to strengthen you and prepare you for the unseen future that lies ahead which one definitely has to go through. There are people that make you feel either good or bad. I will like to term "the bad" here as good since they prepare one for future as I have already indicated.

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ABSTRACT

The air pollutants emitted into the environment from nine industries in Kaduna industrial area located in the Southern part of Kaduna State to Kaduna residential area and its environs have been investigated.

The investigation was carried out with the sole aim of developing a mathematical model that will account for the dispersion of the emitted pollutants from the industrial sites to its immediate environment. Also the quantity of air pollutant available in the industrial area was also investigated to fully assess the impact of the air pollutants from the industrial area on the environment.

The amount of air pollutants measured from the industries for three years period (From 1996 to 1998 inclusive) was analysed and used in the validation of the proposed dispersion model. Also the quantities of air pollutants emitted from the industries were compared with that of FEPA regulated emission limit for each pollutant and it was deduced that some industries at certain point in time exceeded the regulated limits.

The model values showed that to very great degree the proposed air dispersion model is very reliable in controlling the amount of air pollution as it was observed that the major air pollutants such as oxides of nitrogen, sulphur dioxide, carbon monoxide, carbon dioxide and total particulate matter are dispersed in accordance with the law of the dispersion model. Also the simulated values from the computerization of the data also proved this point.

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CHAPTER ONE

INTRODUCTION

Following the industrial revolution and the subsequent rise in pay jobs, the purchasing power of countries increased dramatically. This coupled with the output of science and technology, set the stage for an easier and more comfortable life. It appeared we could have "heaven" on earth; engineering prospered, and technology became a standard requirement for growth in all aspects of economic assessment. If a certain product was desired by a sizeable number of people, we did what we could to produce the goods using the needed production process. Plastics, automobiles, aeroplanes, weapons, leather, shoes and clothing, paints, aerosols, fertilizers, pesticides, synthetic drugs, cosmetics, food preservatives, soaps and detergents, plastics, cement, alcohol, etc are some of the benefits of our intelligence. To support and run industrial machines, we have explored petroleum, coal and nuclear energy.

At the same time, industrialization has created problems like air pollution which is a result of this linear model of production which includes the conversion of raw material into product.

Kaduna metropolis as an industrial city has had its toll of these air pollution problems which is a result of locating industries side by side or not very far from residential areas.

Automobiles, industries and electric power plants are the main sources of air pollutants from uncontrolled processes. Volcanic action, forest fires and dust storms (or sand storms) are natural sources of air pollutants, but these contribute very little compared to the man-made sources. The principal sources of emission in Kaduna are transportation (combustion of fuel), refinery, oils and distillates evaporation in transfer and storage; industrial uses, wood (fuel and refuse burning), incinerators and refuse burning and also solvent evaporation.

Major pollutants are oxides of sulphur and nitrogen entering the atmosphere (Acid rain, fog, dust) and the source these oxides are fossil fuel burning plants, industrial factories, a major source is the exhaust flames of automobiles. Other pollutants are carbon monoxide, hydrogen sulphide, hydrocarbons and particulate matters.

Air pollution causes damages to the vegetation and materials on earth apart from damaging human and animal health, a high degree of air pollution control is essential. But the difficulty to make definite statement about the precise health effects of our pollution is another major problem. This may be due to some problems associated with assessing their damages. Some of these reasons are:

It is usually impossible to determine the degree of exposure of a given individual to a specific pollutant.

Pollutants are numerous and varied and many of them are difficult to detect. Techniques for monitoring pollutants are inadequate, and long term records are almost unavailable.

Research is complicated because pollutants that do not cause problems when tested alone may be dangerous in combination with other pollutants.

Degree of air pollution is correlated with other factors, such as degree of exposure to various kinds of stress, other kinds of pollution and food additives. Such factors must be considered in data analysis.

However, through the rapid development of modern analytical techniques has stimulated an exponential increase in the number and sophistication of industrial cities pollution studies and hence the near perfect strategy of controlling these air pollution hazards through the use of appropriate air pollution model.

1.10 AIMS AND OBJECTIVES

The dangers of gaseous and particulate pollutants to lives and materials particularly those neighbouring industrial side or the environment in general have therefore necessitated the following aims and objectives of this study.

- I. To study the economic effects associated with the emission of air pollutant of the industrial area under study
- II. To identify the effects of these air pollutants on the environment and the ecosystem.
- III. To trace the source of industrial air pollutants, analyse the physical and chemical properties and to know their toxicity on the environment and man by comparing with the standard as stipulated by FEPA (Federal Environment Protection Agency) limits
- IV. To develop a dispersion model of air pollution and use this modelling equation to predict the quantity of pollutants released into our environment with respect to distances. The model is aimed at controlling the emission of air pollutants in Kaduna, an industrial city .

1.20 JUSTIFICATION OF THE STUDY

This study is carried out for the purpose of understanding the economic and environmental problems affecting Kaduna metropolis and environs located near the Kaduna industrial area. This particular aspect will be intensively covered in the result and discussion of results of the case study.

Possible conclusion will be drawn and recommendation made on ways of improving the situation in the area and any other area(s) with similar problem.

1.30 SCOPE OF STUDY

This work focuses on the identification of air pollutants in an industrial city, the causes and control or abatement measures of such pollutant emitted to a safe or tolerable level.

CHAPTER TWO

2.00 LITERATURE REVIEW

Air pollution is defined as the presence in the out door or indoor atmosphere of one or more gaseous or particulate contaminants in quantities, 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 and property.

The increase in global population and the associated industrialization, urbanization and motorization have inevitably led to a greater demand for energy. Production and consumption of both renewable and non-renewable energy has increased steadily since the last century. Historical monitoring of sediments and soils demonstrates how the rise in coal production since the industrial revolution has lead to a concomitant rise in certain pollutant emissions. North America, Europe and the former USSR account for 20 percent of the world population. Yet in 1988 they consumed 68 percent of total primary energy.

Eight-eight percent of the total world energy consumption was provided by fossil fuel, oil (37.6 percent), coal (30 percent) and natural gas (20.2 percent). The combustion of fossil fuels for electricity generation, industrial processes, transport and space heating is the predominant source of primary pollutants in the world. Industrial processes, such as smelting of metal and refining of all, account for a significant proportion of primary pollutant emissions.

The combustion of all carboniferous fuels results in the exothermic oxidation of carbon, hydrogen, Sulphur and nitrogen. If complete combustion is achieved, carbon dioxide (CO₂), water vapour, SO₂, nitrogen oxides (No_x) and volatile and non volatile trace metals such as Arsenic (As), cadmium (cd), lead (Pb) and mercury would be the principal emissions. In

practice, complete combustion does not occur and additional particulate and gaseous pollutants are produced. These include carbon monoxide (Co), and organic and elemental carbon particulate; polycyclic aromatic hydrocarbons (PAH) may also be evolved, either absorbed on to particulate matter or in the gas phase. Further emission may be produced by fuel additives such as tetraethyl lead, tetramethyl lead and various hydrocarbons.

Atmospheric conversion of certain primary pollutants such as SO₂, NO and hydrocarbons results in the production of secondary pollutants. These include photochemical oxidants, nitrogen dioxide (NO₂), ozone (O₃) and peroxyacyl nitrates (PANs) and acid aerosols.

Weather conditions can help reduce the amount of pollutants in the air wind scatters pollutants, rain and snow wash them into the ground. But in many areas, pollutants are put into the air faster than the weather condition can dispose of them. In crowded cities, for example, thousands of automobiles, factories and furnaces add tons of pollutants to a small area of the atmosphere each day. At times weather conditions cause pollutants to build up over an area instead of clearing them away. One such condition called – THERMAL INVERSION – occur when a layer of warm air settles over a layer of cooler air that lies near the ground. The warm air holds down the cool air and prevents pollutants from rising and scattering. A serious problem results when thermal inversion occurs over a city that is pouring tons of pollutants into the air.

Global efforts at mitigating environment pollution exist, but effective international controls are largely lacking where particularly in developing countries like Nigeria; whose chief concerns is to provide such basic needs as food, shelter and employment for it's teeming population.

The effects of air pollution on living beings, vegetation and materials have necessitated its control. Therefore, environmentalist, lovers of the environment and government have been making efforts towards that end.

Other types of pollution include water, Noise thermal and soil (land) pollutants.

2.10 SOURCES OF AIR POLLUTION

The two main source of air pollution are:

1. Natural air – pollution sources
2. Man – made air – pollution sources

Natural air pollution source – The atmosphere is polluted due to natural causes, some of which are

- a) Wind blain dust
- b) Smoke, gases from forest fires
- c) Micro – organisms
- d) Gases and odours from swamps and marshes
- e) Fog
- f) Volcanic as and gases
- g) Pollen
- h) Sea salt nuclei

Man – made source – man’s activities in trying to provide things for the betterment of his stay on earth has also initiated same sources of air pollution.

Those activities that releases man-made air pollution are crushing, grinding, milling, fuel burning, refuse burning, gas flaring, food processing etc to mention just a few.

2.20 CLASSIFICATION OF AIR POLLUTANTS

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The variety of matters emitted into the atmosphere by natural and anthropogenic (man-made) sources is so diverse that it is difficult to clarify air pollutant neatly.

However, usually they are divided into two categories mainly

- a. Primary pollutants and
- b. Secondary pollutants.

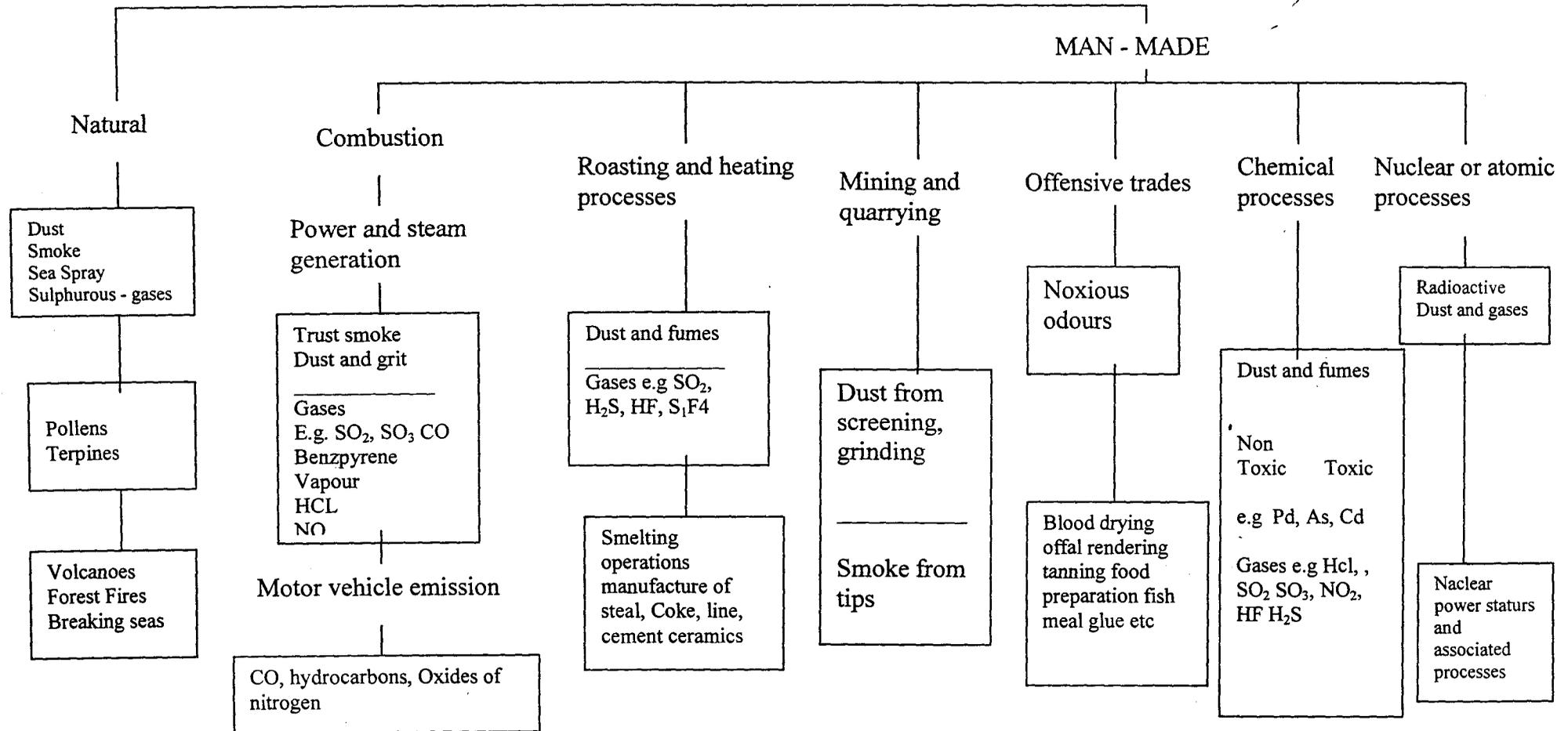
- (a) The Primary Pollutants are those that are emitted directly from the sources. Typical pollutants included under this category are particulate matter such as ash, smoke, dust, fumes, mist and spray; inorganic gases such as sulphur dioxide, hydrogen sulphide, nitric oxide, ammonia, carbon monoxide, carbon dioxide, and hydrogen fluoride, olefinic and aromatic hydrocarbons; and radioactive compounds. Of the large number of primary pollutants emitted into the atmosphere, only a few are present in sufficient concentrations to be of immediate concern. These are the five major types – particulate matter, sulphur oxides, oxides of nitrogen, carbon monoxide and hydrocarbons. Carbon dioxide is generally not considered an air pollutant but, because of its increased global background concentration, its influence on global climatic patterns is of great concern. Also the radioactive pollutants are of specialised nature and their impact also severe.
- (b) The Secondary pollutants are those that are formed in the atmosphere by chemical interactions among primary pollutants and normal atmosphere constituents. Pollutants such as Sulphur trioxide, nitrogen dioxide, peroxy-acetyl nitrate (PAN), ozone, aldehydes, ketones and various sulphate and nitrate salts are included in this category.

Secondary pollutants are formed from chemical and photochemical reactions in the atmosphere.

The reaction mechanisms and various steps involved in the process are influenced by many

factors such as concentration of reactants, the amount of moisture present in the atmosphere, degree of photo-activation, meteorological forces, and local topography.

Fig. 2.00: The Sources of Air Pollution



2.21 CLASSIFICATION OF POLLUTANT ACCORDING TO SOURCE TYPES

Source type refers to natural and anthropogenic (man-made) sources, as well as to additional sub-classifications within each group. Natural sources cover a wide spectrum of types and they are briefly described by the following subdivisions, subsequently they are tabulated as indicated by table 2.20.

COMBUSTION SOURCES

The most important source of anthropogenic pollution with regard to quantity are the products of combustion. The combustion of fossil fuels results in the emission of a variety of pollutants into the atmosphere of which the major ones are SO_2 , NO_x , CO, and particulate matter such as fly ash. Also emitted are small quantities of water vapour and trace metal oxides, e.g. oxides of mercury, lead and cadmium. Incineration of solid combustible wastes and refuse gives off a wide variety of pollutants depending upon waste composition and combustion conditions. These pollutants include aldehydes, Benzpyrene, CO, NO_x , SO_2 , hydrocarbons, ammonia and particulate.

CHEMICAL AND METALLURGICAL INDUSTRIES SOURCES

Next to combustion systems, the major sources of air pollutants are chemical and metallurgical industries. Thus a major and often quite concentrated source of Sulphur dioxide is the roasting and subsequent treatment of non-ferrous sulphide minerals, principally lead, zinc and copper ores. In addition to SO_2 emission, these operations usually produce dust and fumes of primary metal oxides and small quantities of trace metals.

In the case of iron and steel industry, air pollution originates from large scale high temperature processing of coal and iron ore. The major emission sources include ore sintering, coke ovens, and wastewater quenching of hot coke and furnace effluents. Some of the significant emissions are dust, fumes, hydrocarbons, tars, H_2S , and SO_2 . In non-metallic mineral industries like cement, glass, ceramics and refractories, the

operations of mining, crushing, transport and storage of the materials result in the emission of large quantities of hazardous dust.

The chemical process industries are the source of a wide variety of air pollutants emission associated with raw material processing, reaction products and their purification. Some of the pollutants emitted from inorganic industries are SO_2 – H_2SO_4 mist, NH_3 , NO_2 , hydrogen fluoride, HCl gas and H_2S . Synthetic organic chemical industries emit a variety of hydrocarbon compounds and solvents like C_6H_6 , $\text{C}_6\text{H}_5\text{CH}_3$ into the atmosphere.

PETROLEUM REFINING SOURCES

Petroleum refining operations are a major source of air pollution, emitting such pollutants as oxides of Sulphur and Sulphur containing vapours from various stages of the refining process, particulate from catalyst regeneration and recycling, H_2S and mercaptans which are stripped from lighter grades of fuels and hydrocarbons from leaks in valves, pipelines and storage tanks.

PULP AND PAPER INDUSTRY SOURCES

Pulp and paper industry is a notorious source of many air-pollutants emissions into the atmosphere. Sulphur bearing mal-odourous gases such as H_2S , methyl mercaptan, and methyl sulphides are emitted from blow tanks, evaporators and recovery furnace. In addition, combustion of wood waste results in large particulate emission into the atmosphere.

FOOD PROCESSING AND AGRICULTURAL SOURCES

Food processing covers a wide range of activities including drying preservation of food materials and packaging. These activities produce such pollutants as dust from grinding, milling and handling operations, and odours associated with biological decay of food materials. Use of agricultural chemicals for improvements in crop yield, for control of weeds and insects result in emission of pollutants like nitrates and phosphates, pesticides, arsenic and lead particulate into the atmosphere.

TABLE 2.20 CLASSIFICATION OF ANTHROPOGENIC AIR POLLUTION SOURCE

Source Type	Category	Important Sources	Typical Pollutants
Combustion	Stationary	Power plants, industrial boilers, diesel generators, municipal or industrial incineration, refuse burning	Oxides of Sulphur, NO _x , CO, smoke, flyash, trace metal-oxides
	Mobile	Motor vehicle air craft	CO, hydrocarbons, NO _x , SO ₂ , particulates
Roasting and heating processes	Non ferrous metallurgical	Roasting, smelting and refining operations	Dust, smoke, metal fumes (Cu, Pb, and Zn) oxides of Sulphur
	Ferrous metallurgical	Materials handling, ore sintering and palletising coke ovens, blast furnace steel furnace	Smoke, fumes, CO, odours, H ₂ S, organic vapours fluorides
	Non metallic minerals	Crushed stone, gravel, and sand processing, cement, glass, refractories, and ceramic manufacture, coal cleaning	Mineral and organic particulate, SO ₂ , NO _x dust fumes
Chemicals, Petroleum pulp and paper	Petroleum refining	Boilers, process heaters, catalyst regenerators, flares, reactors, storage tanks, compressor, engines	Oxides of Sulphur hydrocarbons, NO _x , particulate matter, CO, aldehydes, ammonia, odours.
	Inorganic chemicals	Sulphuric acid plants, fertilizer manufacture, nitric acid and ammonia plants, phosphoric acid manufacture	SO ₂ , HF, H ₂ S, NO _x , NH ₃ , particulate matter, H ₃ PO ₄ , etc
	Organic chemicals	Plastics, paints and varnish manufacture, synthetic rubber,	Particulate matter, odours, SO ₂ , CO, organic

		rayon, insecticide, soap and detergent manufacture; methanol, phenol etc.	intermediates product gases and vapours, etc.
	Pulp and Paper (Kraft process)	Digester blow system, pulp washers, recovery furnace, evaporators, oxidation towers.	Particulate matter, odourous sulphur compounds (H ₂ S, methyl mercaptan, methyl sulphide) and SO ₂ (sulphite process)
Food and Agriculture	Food Processing	Drying, preserving, packaging	Vapours, odours, dust
	Crop spraying and dusting	Pest and weed control	Organic phosphates, Chlorinated HC, arsenic, lead
	Field burning	refuse burning	Smoke, flyash and soot.

2.30 EFFECTS OF AIR POLLUTION

The effects of air pollution for this study is categorized into two main types namely:-

1. Hazardous effects of pollution in the global – the hazardous effects include Ozone layer depletion, Green house effect and Global warming, and acid rain.
2. Harmful effects of air pollution – The harmful effects of air pollution include its effects on health, vegetation and materials.

2.31 HAZARDOUS EFFECTS OF AIR POLLUTION IN THE GLOBE

The main global hazardous effects of air pollution are acid rain, Ozone depletion and greenhouse effects, which bring about global warming.

OZONE LAYER DEPLETION

Ozone is a gaseous substance made up of three atoms of oxygen (O₃) and is found in its natural form at about 10-30km above the earth surface where it forms a thick layer. The ozone layer serves as a shield, protecting the Earth's surface from most of the ultraviolet radiation found in the sun's radiation. However, this layer may be depleted by reactions involving a variety of compounds, which reach the stratosphere. Of particular concern are the water vapour and nitrogen oxides released by high altitude aircraft, nitrous oxide produced by the action of bacteria in soils (amount of which have become significant with the large scale use of nitrate fertilizers) and chloroflouro-hydrocarbons which are widely used as a aerosol spray propellants and refrigerants.

It is postulated that the combined effect of air craft engine effluents, nitrate fertilizers and halogens would cause considerable depletion of the ozone layer and could result in an increase in ultraviolet radiation reaching the earth leading to crop damage and marked rise in cases of skin cancer, eye damage and affect the productivity of aquatic and terrestrial ecosystems. The recent reports of the ozone hole in the atmosphere over the Antarctica are a cause for great concern.

GREEN HOUSE EFFECT AND GLOBAL WARMING

In the long term, the earth must shed energy into space at the same rate at which it absorbs energy from the sun. Solar energy arrives in the form of short-wave length radiations, Some of this radiation is reflected away by the earth's surface and atmosphere. Most of it however, passes straight through the atmosphere to warm the earth's surface. The earth gets rid of this energy (sends it back into space) in the form of long-wave length, infrared radiation.

The green house effect occurs because there is an atmosphere above the earth's surface. That atmosphere, when it is clear, is largely transparent to solar radiation, but it is largely opaque to long -wave radiation emitted by the surface. Any body in space emits radiation. The wave- length if this radiation is inversely related to the temperature of the body.

Radiation which is emitted by the surface is trapped by the atmosphere above and re-emitted in return and so keeps the earth's surface warm. The glass in the greenhouse works in something like the same fashion, where it keeps the inside temperature warmer than it would otherwise be, hence the name "greenhouse effect", although in some ways it is also a misnomer.

Greenhouse gases in the atmosphere have an important influence on the climate of our planet. Simply stated, greenhouse gases impede the outward flow of infrared radiation. Because of this asymmetry, the earth, its atmosphere and its ocean are warmer than they would be in the absence of such gases.

The main greenhouse gases water vapour, carbon dioxide (CO_2), methane (CH_4), chloro fluorocarbon (CFCs) and hydrogenated chlorofluoro carbons (HCFCs), ozone (O_3) nitrous oxide (N_2O). Most of the infrared radiation emitted upwards by the earth's surface is absorbed in the atmosphere by the gases. They prevent energy from passing directly from the surface out into space.

The increased atmospheric concentrations of greenhouse grasses may increase average global temperatures. The possible warming due to increased concentration of

these gases is refers to as “ Global warming “. Some of the more fundamental aspects of anticipated repercussion of global warming include the following.

Ensure continuos interaction between all the continents and the atmosphere the EL-NINO effect could be devastating.

Global warming is calculated in terms of “commitment” to an equilibrium rise in mean global temperature. There is a lag at two to three decades or perhaps much more between commitment and actual temperature increase, because before fully warming the earth’s surface the green house effect must heat up the oceans (this is known as “ocean thermal lag”). In term of commitment, warming may be estimated as follows:-

$$\Delta T = R \lambda \beta$$

Where

- ΔT - is the equilibrium change in global mean surface temperature (in °C)
- R - is the radioactive forcing above pre-industrial levels (in WM^{-2})
- λ - is to be warming per unit of radiation of radioactive forcing to be expected as the direct impact taking account of feed back (in °C per WM^{-2}), and
- β - is the feed back multiplier (a pure number)

ACID RAIN

Sulphur, nitrogen and substances that form acids in the air when they come into contact with water vapour or droplets, are distributed through some natural processes. Dimethyl sulphides and subsequently sulphur gas are produced by algae in the surface of the sea and indeed may be the main source of the small quantities of sulphur needed as plant nutrients in the soil. Industrial activities, to a disastrous degree in some regions, have increased the natural deposition of sulphur and the acidity of rain. An example is the industrial regions of U.S.A has significantly lower pH than that elsewhere in the country.

There is some speculation that tail smoke stacks and the long -range transport of sulphur (up to 1000km), making the acid rain problem a regional one.

This has been corroborated

1. Increase in global average temperatures;- It now appears that the world is warming at twice the rate projected just five years ago. Scientist believe that by year 2030⁹, global average temperature will be between 3 and 8 degrees fahrenheit higher than it was averaged between 1950 and 1980, or warmer than the earth has been for the past two million years.
2. Changes in regional rain patterns: – at the global level the evaporation or transpiration cycle is expected to speed up. This means that it would rain more, but the rain will evaporate faster, leaving soil drier during critical parts of the growing season. New or worsening droughts especially in the poorer countries could reduce supplies of clean, fresh water to the point where there are major threats to public health.

The harsh weather conditions mentioned above has worsened by the absence of rains, which could have provided the required “cooling effect” for city dwellers, farmers etc whose businesses thrives in the rainy season.

3. Melting glaciers and thermal expansion of sea water:- This will raise sea levels and consequently threaten low-lying coastal areas and small island. The global mean sea level has already risen by around 10 to 15cm during the past century, and global warming is expected to cause a further rise of 95 to 115cm by the year 2100 (with a “best estimate” of 50cm). The most vulnerable land would be the unprotected, densely populated coastal regions of some of the world’s poorest countries, too dangerous aspects of this phenomenon is already being experienced in the Delta and Coastal areas of the country. The bar beach for instance has virtually disappeared as a result of the onslaught of the Atlantic Ocean.

The El-nino phenomenon, which is currently ravaging some nations, is as a result of mass movement of ocean current because of change in pressure system, making area of high pressure belt become that of low pressure and since the ocean are the most vital universal body that by series of studies in Sweden where vast traits of forest and lakes have been or are being destroyed. Acidity kills of fish, bacterial and algae, and the

↙ aquatic ecosystem collapse sterility leaving a clear ultimately dead lake. The environmental effects of acid rain probably include increased leaching of nutrients such as calcium from soil, changes in metabolic rates of organisms which depend on acid or base catalysts, and corrosion of basic materials such as limestone and marble.

Rain and snow are naturally acidic and have a world-wide pH of about 5.6. Man-made acid rain at pH of 4 is forty times as acidic as natural rain, since the pH scale is measured in logarithmic level and lower values indicate increased acidity.

2.32 HARMFUL EFFECTS OF AIR POLLUTION ON HEALTH

The harmful effects of air pollution on health in this study is subdivided into two namely:

1. Effects of Gaseous pollutants on health, and
2. Effects of particulate pollutants on health.

2.33 EFFECTS OF GASEOUS POLLUTANTS ON HEALTH.

The effects of gaseous pollutants on the respiratory system depend on the concentration, period of exposure, and the solubility. High soluble gasses such as sulphur dioxide are ascribed in the upper part of the respiratory system where as relatively insoluble gases like CO, NO₂ and O₃ penetrate deep and reach the alveoli of the lungs. Some of the adverse effects of these pollutants include pulmonary edema, emphysema and prevention of oxygen to the blood.

1. **SULPHURE DIOXIDE**

There is considerable evidence that SO₂ aggravates existing respiratory disease in humans and contributes to their development. Even healthy individual experience broncho-constriction when exposed for a few minutes to level of 1.6ppm.

This condition is accompanied by shallow breathing and an increased respiratory rate.

The acute irritant effects of the gas are confined to the upper respiratory rate.

The primary threat of SO₂ to urban atmosphere may arise not from SO₂ itself but from the changes it undergoes in the atmosphere, such as the formation of H₂ SO₄ and sulphate aerosols. The sulphate particles can be carried deep into the lungs, causing even more severe health problems. SO₂ also be absorbed on small particulate such as the salts of iron, manganese and vanadium present in the atmosphere and this enter the alveoli. There, in the presence of moist air, SO₂ is oxidized to H₂ SO₄ and the particulate acts in enhancing the oxidation process.

2. CARBON MONOXIDE

Carbon monoxide, when inhaled, passes through the lungs and diffuses directly into the blood stream it combines with the red blood pigment called hemoglobin forming carboxy- hemoglobin, COHb. The affinity of carbon monoxide for hemoglobin is 210 times greater than that of oxygen and as a result the amount of hemoglobin available for carrying oxygen for body tissue is considerably reduce. The body tissues are thus deprived of their oxygen supply and death could result by asphyxiation (lack of oxygen). In addition, the presence of COHb in the blood retards the dissociation of remaining oxy- hemoglobin, so the tissues are further deprived of oxygen.

The equilibrium level of COHb may be estimated from concentration of CO below 100ppm in the inhaled air by using the approximate equation thus:

$$\% \text{ COHb in blood} = 0.1 (\text{ppm. CO}) + 0.5$$

A concentration of up to 500ppm in the air, when inhaled for 1hr produces no observable symptoms but a similar exposure to 1000ppm can be dangerous.

Concentrations of 4000ppm and above are fatal, usually within 1hr. Increase COHb in the blood deprives oxygen supply to various vital organs, especially the brain. This lead to impairment of mental performance, visual actuity and other functions. It could inhibit the mucociliary clearance mechanism in the lungs in the presence of other pollutants such as NO₂.

3. OXIDES OF NITROGEN

The major oxides of nitrogen which affect human health are nitric oxide (NO) and nitrogen dioxide (NO₂). NO is not an irritation and at concentrations that occur in the atmosphere it does not show any adverse health effects. However, its main toxic potential results from its oxidation to NO₂.

NO₂ is relatively insoluble and upon inhalation can reach the moisture filled alveoli of the lungs. There it is converted to nitrous and nitric acids which are highly irritating and cause damage to the lung tissues. Long term exposure to concentrations of the order of 1ppm could lead to symptoms resembling emphysema and biochemical alteration in blood. In addition to the direct effects mentioned therein, NO₂ in combination with hydrocarbons acts as the initiator of photochemical smog leading to the production of secondary pollutants like the oxidants. These oxidants are the ones that cause most damage to human health.

4. HYDROCARBONS AND PHOTO CHEMICAL OXIDANTS

At the concentration usually found in urban air, the hydrocarbon cause no adverse effects on human health. Aliphatic hydrocarbons produce undesirable effects only at concentrations 10² to 10³ times higher than those usually found in the atmosphere. No effects have been observed for levels below 500ppm. Aromatic hydrocarbons are more reactive than Aliphatic ones and cause irritation of the mucous membranes.

The major oxidant produced in photochemical smog is ozone contrary to the popular belief, ozone appears to have no effect on the eyes at usual urban concentrations. The respiratory system, however, may respond to a very low concentrations. Many other oxidants are produced in photochemical smog. Particularly are the peroxyaclo nitrate (PANS), causes eye irritation, oxidants such as PAN and peroxybenzoyl nitrate (PBN), irritates the nose and throat, and cause chest constriction which aggravates asthma.

2.34 EFFECTS OF PARTICULATE POLLUTANTS ON HEALTH

The toxic effects of particles can be grouped into three categories:-

- i Interference of inert particles with the clearing mechanisms of the respiratory tract.
- ii Particle act as carriers of adsorbed toxic gases as SO₂ and produce synergistic effects.
- iii Particles may be intrinsically toxic because of their physical or chemical characteristics, such particles belong to metals which are usually found in the atmosphere in trace quantities but may constitute a great health hazard because of the possibility of their concentrations increasing beyond normal levels (0.01 to 3.0 percent of all particulate air pollution).

The trace metals that cause harmful effects on health are lead, cadmium, nickel and mercury.

LEAD

The poisonous effects of lead on human have long been recognized. Lead is a neuro-toxin whose poisoning results in convulsions, delirium, coma, severe and irreversible brain damage and death. Inhaled lead is far more serious than the ingested lead.

The body maintains about the 15-25 µg of lead per 100g of whole blood. At elevated blood lead levels the production of hemoglobin impairment Resulting in oxygen starvation and anemia. High lead levels in the blood may also produce behavioural disorder in children and adults

CADMIUM

Cadmium is a potential health due to its presence in urban atmosphere and cigarette smoke. Cigarette smoking constitutes a major source of cadmium accumulation in the body. The natural cadmium levels in air vary from 0.002 µg/m³ to much higher values of about 0.3µg/m³ found near zinc smelters. Cadmium inhibits the performance of certain enzymes thereby producing hypertension in humans. Exposure to fumes or oxides of cadmium is known to cause cardiovascular disease. In addition, cadmium can interfere

with proper zinc and copper metabolism in the body. Some of the chronic effects are kidney and liver damage and even death.

NICKEL

The adverse effects of nickel are caused mainly due to nickel- carbonyl which is found when finely divided nickel is emitted into an atmosphere containing carbon monoxide. Nickel- carbonyl is also formed in tobacco smoke. Within the lung the carbonyl complex breaks down and deposits finely divided nickel, which may be the main cause of cancer in the lungs. Nickel- carbonyl has shown to cause changes in the alveoli of the lung resulting in respiratory damage symptoms.

MERCURY

Mercury in the atmosphere is only a small part of the overall mercury burden of the environment. It is present in gaseous form in the atmosphere because of its relatively high vapour pressure. The gaseous mercury is washed from the air by rain; a portion of it enters the aquatic systems and the remaining is bound to the soil over the land. In both cases the inorganic mercury is generally converted into its methyl or dimethyl compounds by the action of bacteria.

The physiological effects of mercury poisoning include neurological damage, chromosomal aberrations, and even death. Methyl mercury can penetrate the membranes separating the bloodstream from the brain, causing injury to the cerebellum and the cortex. Another insidious effect of methyl mercury is that it can cross the placental barrier in a pregnant woman resulting in congenital birth defects or the death of the fetus.

2.35 EFFECTS OF AIR POLLUTION ON VEGETATION

Vegetation is more sensitive than animals to many air contaminants, and methods have been developed that use plant response to measure and identify contaminants. The effects of air pollution on vegetation can appear as death, stunted growth, reduced crop yield and degradation of colour. It is interesting to note that some cases of colour damage such as the silverying of leafy vegetables by oxidants, the plant may still be used as food without any danger to the consumer; however, the consumer usually will not buy

such vegetables on aesthetic grounds, so the grower still sustains a loss. Among the pollution that can harm plants are Sulphur dioxide, hydrogen fluoride and ethylene.

2.35 EFFECTS OF AIR POLLUTION ON MATERIALS

The damage that air pollutants can do to some materials is well known.

Ozone is photochemical smog cracks rubber, weakens fabrics, and fades dyes, hydrogen sulphide tarnishes silver. Smoke dirties laundry; acid aerosols ruins nylon hose. Among the most important effects are discoloration, the soiling of goods and impairment of visibility.

1. **Discolouration:** Many air pollutants accumulate on and discolor buildings. Not only does sooty material blacken building, but it can accumulate and become encrusted. This can be hide lines and decorations and thereby disfigures and reduce their aesthetic appeal. Another common effect is the discolouration of paint by certain acid gases. A good example is the blackening of white paint with a lead base by hydrogen sulphide
2. **Corrosion :** A more serious effect and one of great economic importance is the corrosive action of acid gases on building materials, such gases can cause stone surfaces to blister and peel; mortar can be reduced to powder. Materials are also damaged by the corrosive action of some pollutants. Another common effects is the deterioration of tyres and other rubber goods; cracking and apparent “drying” occur when these goods are exposed to ozone and other oxidants.
3. **Soiling of goods:** Wearing apparel are and household good can easily be soiled by air contaminants and the more frequent cleaning thus required can be expensive. Also, more frequent cleaning often leads to a shorter life span of materials and to the need to purchase new goods more often.
4. **Impairment of visibility:** The impairment of atmospheric visibility (i.e decreased visual range through a polluted atmosphere) is caused by the scattering of sunlight by particles suspended in the air. This scattering is more predominant on bright days. Reduction in visibility creates several problems. The most

significant are the adverse effect on aircraft, high way and harbour operations. Reduced visibility can also cause adverse aesthetic impressions which can seriously restrict growth and development of any area. Extreme conditions such as dust storms or sandstorms can actually cause physical damage by themselves.

2.40 **FEPA AND NATIONAL AGENDA FOR INDUSTRIAL EMISSION**

The establishment of the Federal Environmental and protection Agency (FEPA) and more recently the ministry of Environment by the Federal Government though catalyzed by the dumping of toxic wastes of Italian origin in koko in 1988, is none- the- less an affirmation of our governments commitment to environmental protection.

This body called FEPA is set up mainly for the purpose of surveillance and monitoring of industries in order for these industries to obey and abide by these guidelines.

There are many gases in the atmosphere, but the percentage composition varies a great deal. Thus, these have arbitrarily divided into major, minor and trace constitutions.

The table 2.40a shows the constituents for a pollution free dry at ground level.

TABLE 2.40a : AMBIENT AIR QUALITY (POLLUTION FREE AIR)

MAJOR COMPONENTS	% BY VOLUME
Nitrogen	78.08
Oxygen	20.95
MINOR COMPONENTS	-
Argon	9.34×10^{-1}
Carbon Dioxide	3.14×10^{-2}
TRACE COMPONENTS	
Neon	1.181×10^{-3}
Helium	5.24×10^{-4}
Methane	2.0×10^{-4}
Sulphur Dioxide	4.10×10^{-4}
Hydrogen	5.0×10^{-5}
Nitrogen Oxide	2.5×10^{-5}
Xenon	8.7×10^{-6}
Ozone	2.0×10^{-6}
Nitrogen Dioxide	0-trace
Ammonia	0-trace
Carbon Monoxide	0-trace
Iodine	0-trace

Air may contain 0.1 to 5% water by volume: The normal range being 0.1 to 0.3%.

The density of the atmosphere decrease sharply with altitude with over 99% of the gases being found within 30km from the surface of the earth.

The guidelines for allowable levels of pollutants sources represent the maximum allowable levels of pollutants from a site, process stack, vent e.t.c with the objective of achieving a desired air quality. Since the emissions from industries and other sources

have impact on ambient air , it is of utmost importance to prescribe guidelines for safe levels of air pollutants tolerable to humans, aquatic beings and vegetation.

The prescribed emission limits of some air pollution are tabulated in the table (2.40b) below

TABLE 2.40b : AIR POLLUTION LIMIT

AIR POLLUTION	FEPA LIMIT (mg /m ³)
TOTAL PARTICULATE	0.25
NITROGEN OXIDES (NO _x)	0.062 – 0.093
SULPHUR OXIDE	0.026
CARBON MONOXIDE (CO)	11.43
OZONE (O ₃)	0.1 – 0.2
AMMONIA (NH ₃)	0.2
HYDROCARBONS	0.16
DUST	0.60

Source – FEPA

Also for projects, the Environment impact Assessment (EIA) degree of 1992 was promulgated to infuse environmental considerations into development project planning and execution.

2.50 PURIFICATION OF INDUSTRIAL BY PRODUCTS

Industrial by products can be classified into two groups:

1. Suspended particles or aerosol, including dust, smoke, fog; and
2. Gaseous and vapour substances.

The first group includes suspended particles of organic and inorganic origins and liquid particles present in industrial flue gases. Dust particles of inorganic origin include metallic dust and their ores, aluminosilicate, various mineral salts, fertilizer, cement, abrasive, carbides, etc- . Dust particles of organic origin include coal ,wood, tuff,

shale, hides and skins etc. Fog in industrial gases is formed mainly from reaction involving acids especially concentrated H_3PO_4 and H_2SO_4 .

The second group includes gaseous vapour impurities. Most industrial by products are in this group. They include acids, halogens and their derivatives, gaseous oxides, ketones, aldehyde, hydrocarbons, amine, alcohol, pyridine, mercaptan, metal vapour etc.

The need to purify industrial gases is dictated by :

1. Their potential danger to human, animal and plant life
2. Economic loss due to irreversible loss of large a quantity of useful products- organic solvent, metals and their oxides, acidic oxides such as SO_2 , Cl_2 , P_2O_5 , etc.
3. Loss due to corrosion mainly from acidic oxides in air.

The major objectives of purification of industrial flare gases is to reduce the amount of these potentially dangerous compounds to their acceptable threshold limit value (TLV).

Purification techniques can be broadly divided into removal into of dust and removal of gaseous and vapour impurities. All purification techniques are based on the physio-chemical properties of the impurities: their composition fineness, aggregate condition, etc.

2.51 CONTROL OR ABATEMENT OF AIR POLLUTION

The control of air pollution is of utmost concern, if the ambient air quality standards tolerable to humans, animals and vegetation are to be maintained. Also the assessments of air quality trends are needed to design and implement workable control strategies.

Four main approaches have been developed to control air pollution and these are :

CONTROL OF AIR POLLUTION BY ZONING

One method of controlling air pollution is to adapt the zoning system at the planning stage itself. A separate zone or area is set aside for industries thereby reducing the ill

effects of air pollution on the urban dwellers. The zoning of the industries is done based on the type of industries, their function etc.

CONTROLLING AIR POLLUTION BY DEVICES

Due to different process in industries, various-types of gases are liberated along with particulates. To arrest those entering the atmosphere, control devices are used depending on the collection capacity and processes used by the particular industry.

AIR POLLUTION CONTROLLED BY STACKS

When small quantities of air pollutants are released at a source, these can be absorbed without producing noticeable pollution. However, if the quantity of pollutants released is large and air has a limited capacity, the pollution becomes high. If the pollutants are carried away to some distance or taken to high altitudes, they are reduced in concern tradition by diffusion and dilution. The pollutants are taken to high altitude by means of stacks.

AIR POLLUTION CONTROL AT THE SOURCE

The most effective means of dealing with the problem of air pollution is to prevent the formation of the pollutants or minimize their emission at the source itself. In the case of industrial pollutants, this can often achieved by investigating various approaches at an early stage process design and development and selecting those methods which do not contribute to air pollution or have the minimum air pollution potential.

Control of the pollutants at the source can be accomplished in several ways; through the following ways:

1. Changes by way of raw material substitution
2. Modification of process
3. Alteration of particular equipment components.
4. By more effective operation of existing equipment.

1. RAW MATERIAL CHANGES

If particular raw material is responsible for causing pollution, the use of the pure grade of such raw material is often beneficial and may reduce the formation of undesirable impurities and by-products or may even eliminate the troublesome effluent. A typical example of this process/approach is the use of low sulphur fuel in place of high sulphur ones. Burning of natural gas produces less pollution than that of coal.

Ore handling operations usually result in the emission of large quantities of dust into the atmosphere. In steel industry, replacement of raw ore with pelleted sintered ore has gradually reduced dust emission and also helped to reduce blast furnace "slips".

2. PROCESS CHANGES

This involves new or modified techniques of lower atmosphere pollutant emission.

Radical changes in chemical and petroleum refining industries have resulted in minimizing of materials to the atmosphere. The volatile substances are recovered by condensation and the non-condensable gases are recycled for additional reactions. Hydrogen sulphide which was once flared in refineries is now been recycled and used in the Claus process to recover elemental sulphur.

Other examples involving process changing include:

- i. reduction of the formation of nitric oxides in combustion chambers by low excess air combustion in two stages, flue gas re-circulation and water injection
- ii Washing the coal before pulverization to reduce fly-ash emission
- iii Substitute of bauxite flux for fluoride containing fluorspar in the open hearth method.

3. EQUIPMENT MODIFICATION OR REPLACEMENT

In petroleum refineries, hydrocarbons vapour are released into the atmosphere from storage tank due to temperature changes, direct evaporation and displacement during filling. The losses can be minimized by designing the tanks with floating roof cover or by pressuring the tanks. Air pollution from an industrial operations can be reduced by

proper equipment maintenance, house keeping and cleanness in the facilities and premises.

2.52 CONTROL OF SPECIFIC GASEOUS POLLUTANTS

Among the gaseous air pollutants, the sulphur oxides, the oxide nitrogen, carbon monoxide and hydrocarbons have attracted major attention because of their common global occurrence in the atmosphere and their known harmful effects. Hence the need for their optimal control or mitigation.

CONTROL OF SILPHUR DIOXIDE EMISSION

A number of steps are presently being used to remove sulphur from fuels before combustion and from stack gas after combustion, most of these efforts are concentrated on coal because it is the major source of SO₂ pollution. One method involves the removal of elemental sulphur from coal before it is burnt.

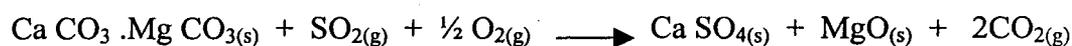
The other more important methods are used to remove SO₂ from stack gas are divided into two namely:

1. The throwing systems; and
2. The recovery systems.

Some of these system are dry while others are wet and involves scrubbing with a water solution.

A dry throw away system which has been used with only limited success involves the injection of dry limestone or dolomite into the boiler followed by recovery of dry lime, sulphites and sulphates.

The overall reaction for such reaction is:



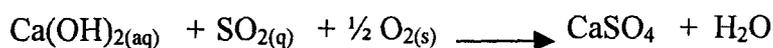
The solid CaSO₄ and MgO are removed by electrostatic precipitators or cyclone separators. This process has an efficiency of 50% for the removal of SO₂ from stack gas.

The most commonly used wet throw away system is the wet limestone process in which limestone is injected into – the boiler and removed along with sulphur-containing

salt in a wet scrubber. This process is an efficient means of reducing SO₂ emissions and has the additional advantage of very effective particle removal. Limestone or dolomite is injected into the boiler furnace where the alkaline earth carbonates are reacted to form oxides. The oxides (CaO) partially reacts with the SO₂ and SO₃ present in the stack gas.

After leaving the furnace, the stack gas containing the oxide, sulphate, SO₂ and fly ash goes through a stack gas scrubber where it contacts water. There, sulphites and sulphates of the alkaline earth metals are formed. In contrast to the dry limestone method, the wet limestone process removes from 90-98% of the SO₂ in the stack gas.

The reaction is



CONTROL OF NITROGEN OXIDES EMISSION

There are two source of nitrogen which contribute to the formation of nitrogen oxides during combustion. One is the atmospheric nitrogen in the combustion air and the other is the bound nitrogen in the fuel itself.

The formation of these gases is favoured by high temperature and excess oxygen concentrations. Therefore these two factors are considered in reducing NO_x emissions from stationary sources.

Reduction of flame temperature to prevent NO_x formation is accomplished by the following methods.

1. The use low excess – air combustion
2. The circulation of cool flue gas
3. The use of the two –stage process
4. Injection of water and steam into the combustion zone.
5. Re-designing of the furnace so as to induce tangential and horizontal firing into the combustion chamber.
6. Other method of reducing nitrogen oxides which are grouped into categories include

- (i) Scrubbing - Scrubbing include Absorption by liquids and Adsorption by solids
- (ii) Catalytic decomposition and reduction.

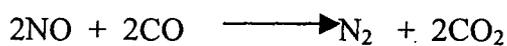
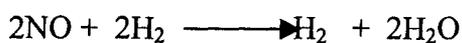
For this study catalytic reduction will be dealt with extensively.

CATALYTIC REDUCTION

As a first step, catalytic decolourizers were developed to reduce NO_x to NO . There are two types of reduction, which termed selective and non-selective. In selective reduction, the added reactant preferentially reduces NO_x and in non-selective reduction, the excess oxygen must be consumed first, selective reduction is to be preferred since it minimizes the amount of reactant required.

Selective reduction can be carried out with H_2 , CO , or NH_3 as the reactant gas.

Typical reactions are:



In non-selection reduction, two types of reactions take place. The first involves the reaction of the fuel with oxygen and nitrogen dioxide, the latter being reduced to nitric oxide.



The second reaction reduces the NO but reduction does not take place until all the oxygen in the flue gas has reacted with the fuel and reducing conditions have been achieved.



In both types of reduction the free Nitrogen emitted is desirable because it is harmless.

CONTROL OF CARBON MONOXIDE EMISSION

Carbon monoxide is formed as an intermediate product of chemical reaction between fossil fuels and oxygen. The formation is due to two reactions:

- (i) In rich mixtures, CO is formed because of insufficient quantity of oxygen.
 - (ii) In lean mixture, CO is formed due to poor turbulence of the fuel and air in the reaction chamber or due to dissociation of CO_2 to CO in high temperature zones.
- Hence, the effects of fuel – air ratio, degree of turbulence and temperature may be significant for CO formation in the hot combustion zone.

Carbon monoxide, unlike some other major gaseous pollutants, does not lend itself to removal by exhaust gas techniques. Hence, the best approach is the control of its formation. The most practical method of reducing the CO emissions from stationary combustion source is by proper design, installation, operation and maintenance of the combustion equipment.

The use of both thermal and catalytic exhaust system reactors designed to change CO to CO_2 is another method of reducing CO.

CONTROL OF HYDROCARBON EMISSION

Four techniques are used to control hydrocarbon emission from stationary source. These techniques are incineration, adsorption, absorption and condensation.

Adsorption process which is the best method of hydrocarbons control will be discussed here.

In the adsorption method, the polluted gas stream is passed through one or several absorbers operated in parallel.

The adsorbers are generally operates in a temperature range between 30 and 60⁰c. The preferred absorbent is granular activated carbon with a mean diameter of 2 to 4mm. The adsorbed vapours are usually removed by passing steam through the system. The mixture of steam and hydrocarbons is liquefied in a condenser and cooled down to ambient temperature in a cooler. The hydrocarbons are separated from the water and recovered for further use. Adsorption units are fairly expensive in teams of capital cost but need little in the way of maintenance or operational manpower.

2.53 PARTICULATE EMISSION CONTROL

In general the term “particulate” refers to all atmospheric substance that are not gases.

They can be suspended droplets or solid particles or mixtures of the two.

Particulate can be composed of inert or extremely reactive materials ranging in size from 100 μm down to 0.1 μm and less. The inert materials do not react readily with the environment nor do they exhibit any morphological changes as a result of combustion or any other process, where as the reactive materials could be further oxidized or may react chemically with the environment. The classification of various particulates may be as follows: Dust, Smoke, Fumes, Mist, Fog, Soot, Flyash, Aerosol etc. The choice of collection device depends upon a number of factors: the physical and chemical characteristics of particulates, the particulate size, concentration in the gas, volume of particulate to be handled , the temperature and humidity of gaseous medium.

2.60 AIR POLLUTION CONTROL EQUIPMENT

Air pollution control equipment are grouped into two namely:

- i. Particulate control equipment, and
- ii. Gaseous emission control equipment.

2.61 PARITCULATE CONTROL EQUIPMENT

There are various type of equipment used for the control of emissions of suspended dust particles from gases. The basic mechanisms of removing particulate matter from gas streams maybe classified as:

- (1) Gravitational settling
- (2) Centrifugal impaction
- (3) Inertial impaction
- (4) Direct interception
- (5) Diffusion
- (6) Electrostatic precipitation.

Equipment presently available, which make use of one or more of the above mechanisms, fall into the following five broad categories:

- (1) Gravitational settling chambers
- (2) Cyclone separators
- (3) Fabric filters (Bag house)
- (4) Electrostatic precipitators, and
- (5) Wet collectors (scrubbers)

The mode of operation of some of these equipment are mentioned below:

CYCLONES

Gas flow are induced by a fan. The gas flowing through the cyclone cause increase in the velocity of dust particles suspended in the gas, thereby increasing the forces acting on these particles beyond normal gravitational forces. The particles spin rapidly under the action of centrifugal force, which make to impinge onto the walls of the cyclone where they loose momentum and pass downwards through the conical base of the cyclone, whilst the cleaned gas passed out through a centrally placed cortex tube

ELECTROSTATE PRECIPATOR

The precipitator consist of collector electrodes in the form of vertical plates, or tubes with discharge electrodes, which are usually wires. The collector electrodes are normally connected to a D.C supply of negative polarity. The voltage between the discharge electrodes and the collector electrode is increased gradually, until a corona discharge takes place usually in the range of 30,000 to 50,000 volts.

The dust particle in the as stream are charged in an electric dust and are attracted towards and deposited on the earth electrodes collection hopper for subsequent transfer back to the raw-mill storage silos and re-use in the kiln system.

BAG HOUSE

Dust particles are separated from the gas stream and are collected on filter (fabric filter) bags, arranged vertically against the direction of the gas flow. The semi-porous

medium allows the clean gas to pass through the system and the dust falls down into collection chutes. This process is initiated by intermittent compressed air purging into the jet tubes connected to the bags.

2.62 GASEOUS EMISSION CONTROL EQUIPMENT

Several equipment are available for the purification of gaseous air pollutants. The basic mechanisms of removing gases pollutants from air stream are:

- (1) Absorption
- (2) Adsorption
- (3) Condensation
- (4) Incineration

Equipment presently available, which make use of one or more of the above mechanisms, fall into the following categories:

- (1) Absorber
- (2) Adsorber
- (3) Condenser
- (4) Incinerator

The mode of operation of these equipment are mentioned below:

ABSORPTION

Gas-liquid absorption process are normally carried out in vertical, counter current flow through packed, plate, or spray towers. For absorption of gaseous stream, good liquid – gas contact is essential and is partly a function of proper equipment selection. In this process a gas mixture is contacted with a suitable liquid for the purpose of preferentially dissolving one or more of the constituents of the gas. The constituents are thus removed or partially remove from the gas into the liquid, which absorbs and makes them harmless.

ADSORPTION

Adsorption is a surface phenomenon whereby the gaseous pollutants in the air streams are attracted to and adhere to the surface of the adsorbent. Activated carbon, with its extensive internal microporous structure, is the most commonly used adsorbent either in powdered or granular form. Adsorption is generally carried out in large, horizontal fixed beds often equipped with blowers, condensers, separators, and controls.

INCINERATION

This is the method of providing a clean, odourless effluent if the exit – gas temperature is sufficiently high for the process. For processes producing contaminated gas streams that have no recovery value, incineration may be the most acceptable route when gas streams are combustible.

Incineration leads to air pollution unless the plants is designed, equipped and operated to comply with air pollution standards. Air pollution can be controlled by installation of proper control equipment.

CHAPTER THREE

3.00 EXPERIMENT METHODOLOGY

Generally, all the experimental methods carried out in this project research are aimed at analysis and determining the extent to which Kaduna South industrial area and its adjoining residences including kakuri and its environs has been polluted by the release of gaseous pollutant emitted form the various industries that make up the industrial area.

These methods are specifically employed to determine certain physical and chemical characteristics of air pollutants. The results obtained are analyzed by the environmental and safety section of the industries with the collaboration with the kaduna Environment protection Agency (KEPA). The results obtained are then compared to that of FEPA standard allowable air pollution limit, most of the methodology used here are as a remit those gotten the literature (text).

3.10 EXPERIMENTAL ANALYSIS OF AIR POLLUTANTS

The experimental analysis involves various determination of the various Characteristics of the air pollutant samples which are subjected to various physical and chemical methods of analysis.

In chemical methods, the pollution been analysed undergoes chemical transformations and the products is then analyzed with an appropriate analytical technique. In the so called wet chemical analysis the pollutant is absorbed in a liquid for a given period of time, which is then treated with a reagent resulting in a change of colour or the formation of another product. The colour intensity or the product concentration is related to the original pollutant concentration.

In the physical methods of measurement, a physical property of the pollutants is exploited – such as the ability of the gas to absorb infrared radiation. The amount of radiation is then detected.

The physical and chemical method of analysis of some gaseous and particulate pollutants are as presented below.

3.11 DETERMINATION OF SULPHUR OXIDE, SO₂

(a) Reagents

Sodium tetrachloromercurate,

Formaldehyde

Bleached pararosaniline

Ethylene diamine tetra acid (EDTA),

Sulphamic acid

Dilute solution of hydrogen peroxide, and

Dilute sulphuric acid.

(b) Apparatus

Colorimetric meter

Photometric meter

(c) Procedure

SO₂ from a measured quantity of air was absorbed in a solution of sodium tetrachloromercurate to form a stable and non-volatile dichlorosulphitomercurate complex. This was then reacted with Formaldehyde and bleached pararosaniline, yielding a magenta-coloured pararosaline sulphonic acid product. The intensity of this acid, which is detected by photometric methods, is proportional to the concentration of SO₂.

To remove iron and other heavy metal salts interference which lowers SO₂ concentration, EDTA was added to sequester such interference. Nitrogen oxide interference was also eliminated by adding a small amount of sulphamic acid which destroys the nitrate iron prior to the desired colour formation as detected by the colorimeter.

3.12 DETERMINATION OF NITROEN OXIDES

(a) Reagent

Ozone

(b) Apparatus

Chemiluminescent analyzer

(c) Procedure

Ozone was passed into the gaseous oxides but it only reacts rapidly with NO to form NO₂ and oxygen.

The emitted radiation from the reaction was received by a photomultiplier tube whose output was amplified and fed to a recorder. The intensity of radiation is proportional to the amount of nitric acid. The thermal converter incorporated into the chemiluminescent analyser enables for the measurement of the level of NO₂ content produced by taking the difference in readings when the gas flows through the converter and when it was by passed.

3.13 DETERMINATION OF CARBON MONOXIDE, CO

(a) Reagent

Non-absorbing Nitrogen gas contained in the reference cell

(b) Apparatus

Non dispersive infrared analyzer (NDIA), consist of a sample cell, two infrared source and a detector with two compartments.

(c) Procedure

An optical chopper alternatively exposes the reference and sample cells to the infrared sources. The reference cell passes almost all of the infrared energy onto one compartment of the detector cell, while a varying amount of infrared energy, inversely proportion to CO concentration in the sample cell, reaches the other detector compartment, the CO contained therein expands causing a pressure differential across the diaphragm which in turn causes the diaphragm to pulse back and forth in phase with the chopper action. (The magnitude of the diaphragm distention is a function of the

absorbing CO concentration in the sample cell). The mechanical movement of the diaphragm is converted into an electrical signal which is amplified and recorded.

3.14 DETERMINATION OF HYDROCARBONS

Hydrocarbon pollutants can be determined as 'total hydrocarbons' or an individual chemical species. The most abundant hydrocarbon; methane, is not a hazardous air pollutant and as such the total hydrocarbon content is generally reported on a non-methane basis. The total hydrocarbon content is most commonly determined by the flame ionization technique.

(a) Reagent

Hydrogen, and Air or Oxygen

(b) Apparatus

- Flame ionization detector
- Charcoal column adsorber

(c) Procedure

The sample of gas containing the hydrocarbon was injected into the flame created by burning hydrogen in either air or oxygen in the flame ionization detector (FID). The presence of hydrocarbons makes the flame to produce a complex ionization in which large number of ions are present. An electric field was set up in the vicinity of the flame by making the burner jet positive with respect to a wire loop. The electric induces ion migration on such a manner that a small ionization current was established between the electrodes, and this current is proportional to the concentration of ion in the flame. The current was amplified and displayed on an output meter.

The analysis of the non- methane hydrocarbon present is accomplished by a differential measurement. The sample is passed through a charcoal column which was saturated with methane but it is still capable of retaining other hydrocarbons. This column is then used with the FID as an analyzer for the

analysis of methane only. By differences between the results obtained, the non-methane hydrocarbons is assessed.

3.15 DETERMINATION OF PARTICULATE MATTER

Several methods of measurement of particulate emissions in flue gases falls into two categories: Opacity measurements and mass measurements. The mass measurement is of utmost importance and it is discussed below.

(a) Reagent

None

(b) Apparatus

Piezoelectric monitor

(c) Procedure

Particles in the sample stream was electrostatically deposited onto an oscillating quartz crystal. The resonant frequency of the particulate and this added weight of the particulate matter and this shift was detected and used to provide a signal which is proportional to the mass present.

CHAPTER FOUR

4.0 MODEL AND MODELLING

A model can be defined as a simplified representation of certain aspect of a real system. A model is used to capture the essence but not the detail of a system. All that is needed in modelling are techniques and insight in addition to intuition, ingenuity and/or creative imagination. Also in modelling no specific rules or procedures or definite answers. Therefore, there are no right and proper models. We are not in the same situation as with arithmetic or algebra, where, to each question there is one correct answer. Many different models can be developed for tackling the same problem (it is also true and a remarkable demonstration of the power of mathematics, that the same abstract model can often be used for quite different physical situations) some models may be “ better” than others in the sense that they are more useful or more accurate, but this is not always the case. Generally the success of a model depends on how easily it can be used and how accurate are its predictions. Note also that any model have a limited range of validity (boundary conditions) and should not be applied outside this range

4.10 TYPES OF MODELS

The different types of models that exist falls on the following categories;

1. Iconic models
2. Analogue models
3. Theoretical (physical) models
4. Mathematical (symbolic/ Empirical) models.

1. **ANALOGUE MODELS** – These models involves the use of one characteristic of a system to represent a characteristic of another system. For example using pendulum to represent public opinion poll.
2. **ICONIC MODELS** – These are visual images or representation of the real system ,i.e., maps, graphics, charts, photograph, effigy etc.
3. **THEORETICAL (PHYSICAL) MODELS-** These are models developed using the simple principles of chemistry, physics and any other scientific means.
4. **MATHEMATICAL (SYMBOLIC/EMPIRICAL) MODELS** – A Mathematical model is a model created using mathematical concept such as functions and equations or is the use of various symbolic usually algebraic to represent the variables or inter- relationship of a system. When we create

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mathematical models, we move from the real world into the abstract world of mathematical concept which is where the model is built. We then manipulate the model using mathematical techniques or computer aided numerical computation. Finally we re-enter the real world, taking with us the solution to the mathematical problem, which is then translated into a useful solution to the real problem.

Mathematical models can be useful in process analysis and control in the following ways.

- i. To improve the understanding of the process – process models can be analysed or useful in a computer simulation of the process to investigate process behaviour without the expense and perhaps, without the unexpected hazards of operating the real process.
- ii. To design the control strategy for a new process – a process model allows alternative control strategies to be evaluated, for example, the selection of the variables that are to be measured (controlled) and those that are been manipulated.
- iii. To select controller settings – A dynamic model of the process may be used to develop appropriate controller settings, either via computer simulation or by direct analysis of the dynamic model.
- iv. To design the control law – Model control techniques often incorporate a process model into the control law.
- v. To optimise process operating conditions – In most processing plant there is an incentive to adjust operating conditions periodically so that the plant maximises profit or minimises cost.

All the types of models mentioned could be :

Summarised into two, namely:

- (1) Deterministic (predictive) models
- (2) Stochastic models

(1) Deterministic or predictive models – this is when the outcome of the model is a direct consequence of the initial conditions of the problem. This directness is not affected by any arbitrary external factors, or, in particular random factors. Very often, but not always, this kind of model involves differential equations in which time is the independent variable.

(2) Stochastic models – This is reserved for those situations where a random effect plays a central role in the problem investigation. Many models of

this kind are essentially 'next-events' models often involving queues and services.

4.20 METHODOLOGY OF MODELLING

Modelling methodology is a process, which involves a number of clearly identifiable stages. Any model must have a definite purpose that is clearly stated at the start. The methodology of a model involves the following:

1. Start to identify the real problem – This involves asking question on the problem to be solved. Those question to be asked include the purpose and objective, the outcome to be judged, whether there is one particular unique answer to be found, classifying the problem whether it essentially deterministic or stochastic and finally whether simulation could be done.
2. Mathematical formulation – This involves examining all the relevant facts and data. It also involves making assumptions. Collecting data and examining them for information and explaining the behaviour of the variables. Denoting each variable by an appropriate symbol (like graphs, diagrams charts etc) and assign units. Finally drawing up relations and equations connecting the problem variables, using your mathematical skills, e.g. proportionally, linear and non-linear relations, empirical relations, input and output principle, and differential equations, matrices, probability, statistical distributions, etc.
3. Evaluate or obtain the mathematical solution of the model – This involves the use of algebraic and / or numerical methods, calculus and graph. Writing computer programmes or using a prepared package if suitable. Use a simulation package if necessary and finally extracting values for the variable that are needed, either tabular or in graphical form.
4. Interpret the mathematical solution – This involves examining the results obtained from the mathematics whether the values of the variables got have the correct sign and, size, whether they increase or decrease when they should and whether a certain graph be linear or not etc.
5. Compare with reality – Comparison here involves testing the result obtained against real data. Also evaluating the model whether it has fulfilled its purposed and whether the interim results suggest that more accuracy is needed by re-running with an improved model .This is important; very often the “modelling cycle” is transverse a number of times before the results are satisfactory.

6. The last stage of the model methodology involves writing a report and /or presenting the result obtained. This involves constructing the report so that the important features are clear and the result we want to be read stand out.

4.30 SIMULATION

The implementation and validation of a model is the simulation. Simulation represent the application of modelling techniques to real systems, this enables information on the system to be gained without either construction or operating the full-scale system under consideration.

Simulation can be used to predict the effect of changing conditions to optimise operation quickly and safely and it can be used to provide in-depth knowledge about a complete system behaviour, to improve and facilitate cost calculation and planning of operation.

Simulation methods come in two types viz.: Digital and analogue simulation. Of these two types, digital simulation which involves the use of code and programme are more in use since they can be implemented on modern computer with exceptional speed and accuracy.

4.40. TRANSPORT OF POLLUTANTS

Pollutants transportation is accomplished by two distinct physical mechanisms, advection and diffusion. The first describes the entrainment of the pollutant material in the ambient flow and its transport either as solution or as suspension by the fluid, with velocity equal to the fluid velocity (assuming negligible resistance to the flow)

The second mechanism describes, in the case of laminar flow, the Brownian motion of the pollutant molecules, resulting in the continuous increase of the area that the pollutant originating from a local source occupies. In the case of turbulent flow, the motions at molecular level become negligible before the similar process of entraining pollutant masses in turbulent eddies, leading to the same but at a much faster rate.

The rate of diffusion even in the case of turbulent flow can be described by a diffusion coefficient, according to the Brussinesq approximation¹. This is the eddy diffusion coefficient, analogous to the eddy viscosity coefficient and some orders of magnitude greater than the molecular diffusion coefficient, a function, in general, of the hydrodynamics of the pollutant carrying fluid. It will be symbolised by K (with unit in m^2/s)

The proportion by which the two mechanisms of advection and diffusion contribute to the final pollutant transport is quantified through the Peclet number $\{P_e\}^2$

$$P_e = \frac{UL}{K}$$

Where U(m/s) is the characteristic velocity of the transporting fluid, L (m) is a characteristic length of the flow and K(m²/s) the diffusion coefficient. Value of P_e , $0 [P_e] > 1$ demonstrate that the advection dominate over the diffusion.

4.50 METHODOLOGY OF AIR POLLUTION MODEL

The methodology of this model was based on the transport theory known as the 'K- theory' developed by Taylor¹⁰, Richardson¹¹ and Roberts¹², which in turn involves the use of the concept of mixing length. The basis of this eddy diffusion model is on the dispersion of the pollutant from the source (i. e. the industries emitting it) to the surrounding environs some distances away.

4.51 ASSUMPTION MADE ON THE AIR POLLUTANT DISPERSION MODEL

The assumptions made during the course of the development of this model are as stated below:

1. A mole of any gas occupy the same volume, i.e. the stack gases will occupy the same volume in the industrial area.
2. From Dalton's law of partial pressure that states that for a mixture of gases the total pressure is equal to the sum of the partial pressure of the constituent gases; in the same vein it can be deduced that the total concentration of pollutants in an environment is a sum of the individual concentration of each gaseous pollutant e.g. SO₂, H₂S, HC, CO₂, and CO.
3. We are assuming that the movement of the gas (diffusion) as a result of wind speed is a horizontal movement i.e. we are considering the X and Y axes for this model : for that is how damage is caused to the inhabitants of the environment.

In essence, assumption of a nearly horizontal flow is valid for the model.

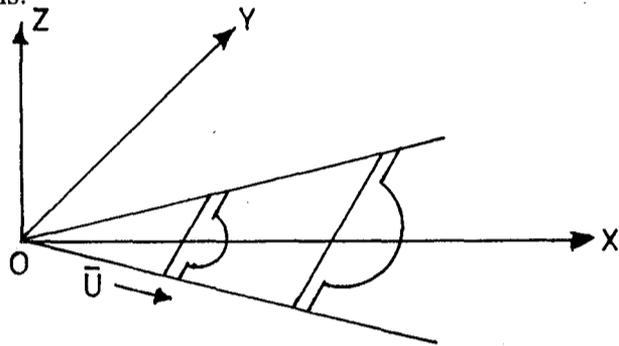
In the near field the phenomenon may have a fully three-dimensional nature (e.g., a bouyant plume developing from stack emission), but in the far field the

horizontal motion prevails over the vertical. In the far field the phenomenon can be two dimensional, in a horizontal sense.

- (4) The stack gases emitted from the industries the atmosphere are not reactive. I.e. there is no form of reaction between the pollutant.

4.52 DEVELOPMENT OF THE MATHEMATICAL AIR DISPERSION MODEL

Fig 4.52: cross section of a continuous point source showing concentration profiles in the y and x directions.



The mathematical model of pollution transport is written with respect to the unknown scale – function of the concentration of pollutant $\rho(x, y, z)$ as indication of the figure 4.52. The concentration is measured either as the volume of fluid (example of unit are ppm, mg per litre, number of escherichia coli per litre etc). The model consists of one equation describing the conservation of the mass of pollutant during its motion.

Examining the balance of the in-flowing and out-flowing mass from two cross-sections in a simple one-dimensional flow⁴ with velocity U , it is found that

$$\frac{\partial \rho_A}{\partial t} = \frac{\partial \rho_A}{\partial t} + \frac{\partial (U \rho_A)}{\partial x} = \frac{\partial}{\partial x} \left[K_{xx} \frac{\partial \rho_A}{\partial x} \right] \text{-----(1)}$$

Where K_{xx} is the eddy diffusion coefficient. In the most general cases of three-dimensional pollutant transport equation (1) expands according to the equation (2) below

$$\begin{aligned} & \frac{\partial \rho_A}{\partial t} + \bar{u} \frac{\partial \rho_A}{\partial x} + \bar{v} \frac{\partial \rho_A}{\partial y} + \bar{w} \frac{\partial \rho_A}{\partial z} \\ &= \frac{\partial}{\partial x} \left[K_{xx} \frac{\partial \rho_A}{\partial x} \right] + \frac{\partial}{\partial y} \left[K_{yy} \frac{\partial \rho_A}{\partial y} \right] + \frac{\partial}{\partial z} \left[K_{zz} \frac{\partial \rho_A}{\partial z} \right] \text{-----(2)} \end{aligned}$$

Where ρ_A is the mass concentration of a species A

\bar{U} , \bar{V} and \bar{W} are the velocity component in the x, y and z directions respectively;

And K_{xx} , K_{yy} and K_{zz} are the eddy diffusivities in the x, y and z directions respectively.

Our aim as in the development of this model is to find the concentration levels of pollutants at given distances from the plume of a stack. This will help to determine the safe minimum distance of residential building from an industrial area and prescribe the release limit of a pollutant from its source on the basis of acceptable recipient level of concentration.

In our case, eqn (2) can be further simplified without damage to the intension of the mathematical model. Therefore, the following assumptions can be made: -

(i)
$$\bar{V} = \bar{U} = \frac{\partial \rho_A}{\partial t} = 0$$

(ii) The pollutants are chemically inert and K_{xx} , K_{yy} and K_{zz} are constant throughout atmospheric space with the above assumptions, eqn (2) reduces to: -

$$\bar{U} \frac{\partial \rho_A}{\partial x} = K_{xx} \frac{\partial^2 \rho_A}{\partial x^2} + K_{yy} \frac{\partial^2 \rho_A}{\partial y^2} + K_{zz} \frac{\partial^2 \rho_A}{\partial z^2} \quad \text{--- (3)}$$

Where \bar{U} is the mean velocity of the wind.

Often, the transport of pollutants in the x- direction by the wind is dominant over turbulent diffusion in the x - direction. That is,

$$\bar{U} \frac{\partial \rho_A}{\partial x} > K_{xx} \frac{\partial^2 \rho_A}{\partial x^2}$$

Incorporating this assumption in (3), we arrive at

$$\bar{U} \frac{\partial \rho_A}{\partial x} = K_{yy} \frac{\partial^2 \rho_A}{\partial y^2} + K_{zz} \frac{\partial^2 \rho_A}{\partial z^2} \quad \text{--- (4)}$$

For our purpose, the x and y axes will be the ground surface or the parallel plane to the ground surface from which the stack rises.

The z – direction is the vertical line perpendicular to this plane i.e. the x – y plane.

Since our purpose is to find the pollution levels at linear distances from the stack (i.e. from the point of emission) to residential areas, the z component of eqn (4) is of no practical interest to this work and thus neglected. With this assumptions, we have it that

$$\frac{\partial \rho_A}{\partial z} = 0 = \frac{\partial^2 \rho_A}{\partial z^2}$$

$$\text{Therefore, } \bar{U} \frac{\partial \rho_A}{\partial x} = K_{yy} \frac{\partial^2 \rho_A}{\partial x^2} \text{-----(5)}$$

This model is a predictive model that should tell the concentration levels at selected linear distances x and y from the plume given the proper boundary conditions. It is also a model that acts as a control of how much emissions industry should release into the atmosphere if we are to have a habitable area.

4.53 NUMERICAL SOLUTIONS, CRITICAL PRESENTATION OF FINITE DIFFERENCE SCHEMES

From the field equation (2) of the mathematical model for the turbulent advective diffusion of a conservative and non-conservative pollutant, it can be shown that the mathematical problem is the solution of a linear partial Differential equation (LPDE) of mixed type (hyperbolic and parabolic). The advective is accomplished with celerity equal to the fluid velocity (u, v) while the diffusion is done at a rate analogous to the assumed **k** values. According to pëdet values, the hyperbolic or parabolic parts prevail.

It can be said a priori that the major problem in the numerical solution of the model is control of the numerical errors intruding in the solution in the Form of numerical diffusion or dispersion. The explicit Forms of finite difference schemes are subjected to Stability Criteria regarding the space discretisation steps Δx .

Now let ρ_A be simply represented a ρ , we proceed to find the solution of partial differential equation,

$$\bar{U} \frac{\partial \rho}{\partial x} = K_{yy} \frac{\partial^2 \rho}{\partial y^2} \text{ -----(5a) by the finite difference method}$$

$$\text{Now, } \frac{\partial \rho}{\partial x} = \frac{\rho_{i+1,j} - \rho_{i,j}}{\Delta x} \text{ -----(6)}$$

$$\text{also, } \frac{\partial \rho}{\partial y} = \frac{\rho_{i,j+1} - \rho_{i,j}}{\Delta y} \text{ -----(7)}$$

$$\begin{aligned} \frac{\partial^2 \rho}{\partial y^2} &= \frac{\partial}{\partial y} \left(\frac{\rho_{i,j+1} - \rho_{i,j}}{\Delta y} \right) \\ &= \frac{\rho_{i,j+1} - \rho_{i,j} - \rho_{i,j} + \rho_{i,j-1}}{\Delta y} \\ &= \frac{\rho_{i,j+1} - 2\rho_{i,j} + \rho_{i,j-1}}{\Delta y^2} \text{ -----(8)} \end{aligned}$$

$$\text{From equation (5a), } \bar{U} \frac{\partial \rho}{\partial x} = K_{yy} \frac{\partial^2 \rho}{\partial y^2}$$

$$\text{so, } \bar{U} \left(\frac{\rho_{i,j+1} - \rho_{i,j}}{\Delta x} \right) = \frac{K_{xx}}{\Delta y^2} (\rho_{i,j+1} - 2\rho_{i,j} + \rho_{i,j-1})$$

$$= \frac{\bar{U}}{k_{xx}} (\rho_{i,j+1} - \rho_{i,j}) = \frac{\Delta x}{\Delta y^2} (\rho_{i,j+1} - 2\rho_{i,j} + \rho_{i,j-1}) \text{ -----(9)}$$

Let $\lambda = \frac{\Delta x}{\Delta y^2}$

where

Δx is the mesh length along the x – axis and

Δy^2 is the mesh length along the y – axis.

For stability, we must have $\lambda \leq \frac{1}{2}$

$$\frac{\bar{U}}{\text{So, } K_{xx}} \left(\rho_{i+1,j} - \rho_{i,j} \right) = \lambda \left(\rho_{i,j+1} - 2\rho_{i,j} + \rho_{i,j-1} \right)$$

Using a superscript format,

$$\frac{\bar{U}}{K_{xx}} \left(\rho_j^{i+1} - \rho_j^i \right) = \lambda \left(\rho_{j+1}^i - 2\rho_j^i + \rho_{j-1}^i \right)$$

$$\rho_j^{i+1} - \rho_j^i = \frac{\lambda K_{xx}}{\bar{U}} \rho_{j+1}^i + \left(-\frac{2\lambda K_{xx}}{\bar{U}} \right) \rho_j^i + \frac{\lambda K_{xx}}{\bar{U}} \rho_{j-1}^i$$

$$\rho_j^{i+1} = \frac{\lambda K_{xx}}{\bar{U}} \left(\rho_{j+1}^i + \rho_{j-1}^i \right) + \left(1 - \frac{2\lambda K_{xx}}{\bar{U}} \right) \rho_j^i \text{ -----(10)}$$

This scheme is conditionally stable; stability holds for $\lambda \leq \frac{1}{2}$

Equation(10) is the modeling formula.

4.60 DIFFUSION COEFFICIENTS (DIFFUSIVITIES) OF GASEOUS POLLUTANTS.

Diffusion coefficients are needed in the design of mass transfer process, such as gas absorption, adsorption and distillation.

For most design work the values will have to be estimated. The equation developed by Fuller et al (1966)⁷ is easy to apply and gives reliable estimates.

$$K_v = 1.013 \times 10^{-7} T^{1.75} \left(\frac{1}{M_a} + \frac{1}{M_b} \right)$$

$$P \left((\sum_a v_i)^{1/3} + (\sum_b v_i)^{1/3} \right)^2$$

Where k_v = diffusivity, m^2/s

T = Temperature, K

M_a, M_b = molecular weights of components a and b

P = Total pressure, bar.

$\sum_a v_i, \sum_b v_i$ = the summation of the special diffusion volume coefficients for components a and b, given in the table below.

Table 4.50a: Special atomic diffusion volume

Atomic and Structural diffusion volume increment			
C	16.5	Co	18.9
H	1.98	Co ₂	26.9
O	5.48	N ₂ O	35.9
N	5.69*	NH ₃	14.9
Cl	19.5*	H ₂	12.7
S	17.0*	CCl ₂ F ₂	114.8
Aromatic or hetrocyclic rings	20.0	SF ₆	69.7*
H ₂	7.07	Cl ₂	37.7*
He	2.88	Br ₂	67.2*
		SO ₂	41.1*

* value based on only a few data points.

Now, using this table 4.50a and the equation for calculating diffusivities the diffusion coefficients of SO₂ and N₂O and other gases were calculated in (Appendix I) and presented in table (4.50b).

Table 4.50b - Diffusivities of some gaseous pollutants.

POLLUTANTS	K (m ² /s x 10 ⁻⁶)
SO ₂	12.6
CO	19.5
CO ₂	16.4
N ₂ O	14.1
Ammonia	28.0
Benzene	8.8

4.61 BOUNDARY CONDITIONS.

$$\rho \longrightarrow 0 \text{ as } x \longrightarrow \infty$$

$$\rho \longrightarrow \rho_0 \text{ as } x \longrightarrow 0$$

$$\frac{\partial \rho}{\partial x} \propto -\rho$$

$$= \frac{\partial \rho}{\partial x} = -K_{xx} \rho$$

$$\frac{\partial \rho}{\partial x} = -K_{xx} \rho$$

$$\int_{\rho_0}^{\rho} \frac{\partial \rho}{\rho} = - \int_0^x K_{xx} dx$$

$$\left(\ln \rho \right)_{\rho_0}^{\rho} = -K_{xx} \cdot x$$

$$\ln \rho - \ln \rho_0 = -x K_{xx}$$

$$\ln \left(\frac{\rho}{\rho_0} \right) = -x K_{xx} \quad \frac{\rho}{\rho_0} = e^{-x K_{xx}}$$

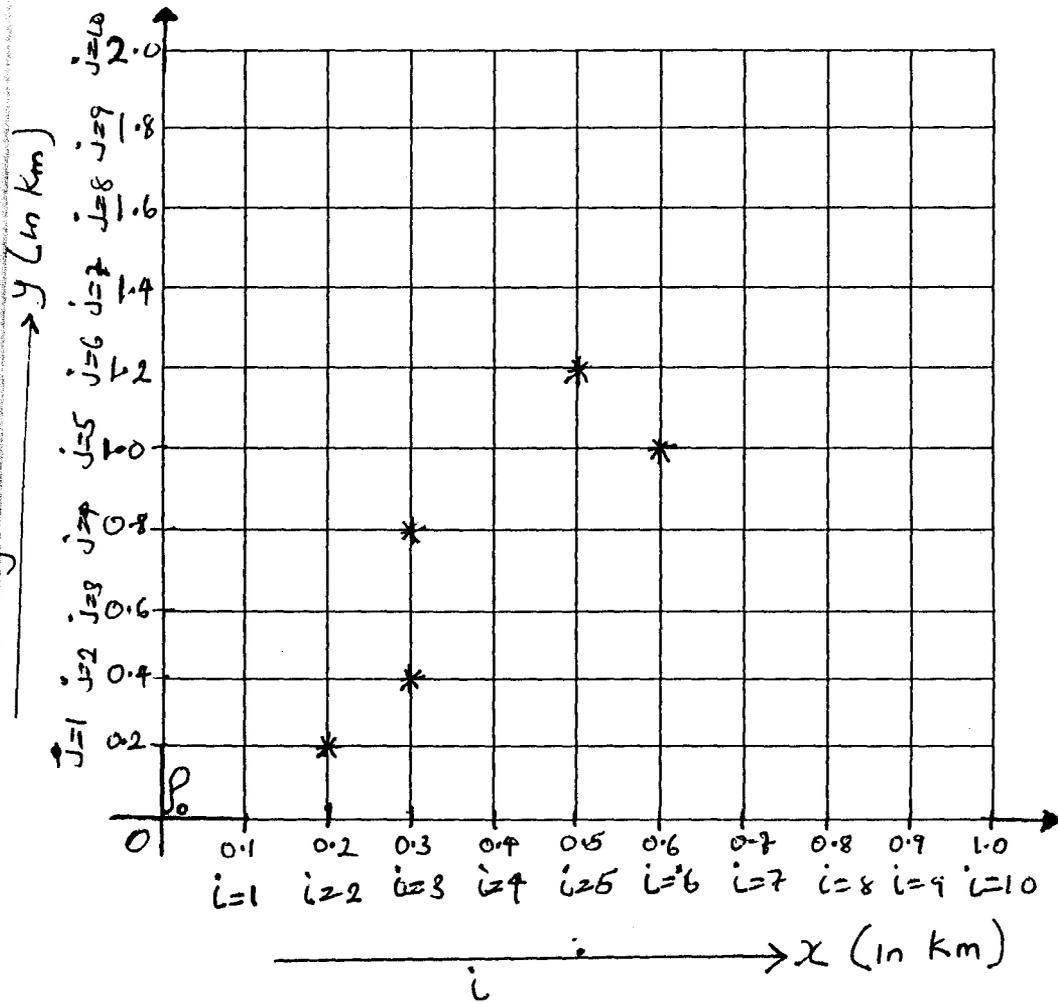
$$\rho = \rho_0 e^{-x K_{xx}} \quad \text{--- (11)}$$

Eqn (11) is the boundary condition along the x-axis

Where $K_{xx} = K_{yy} = K$

The Figure overleaf illustrates how the emitted pollutant from the industrial area disperses with increasing distance according to the modelling equation.

Figure 4.61: A DIAGRAM OF CONCENTRATION OF EMITTED POLLUTANTS WITH RESPECT TO DISTANCE.



x and y are distances.

Where $i = 1, 2, 3, 4, 5 \dots$

At $x = 0.1, i = 1$

$x = 0.2, i = 2$ etc.

Also where $j = 1, 2, 3, 4, 5 \dots$

At $y = 0.2, j = 1$

At $y = 0.4, j = 2$ e.t.c

The points marked * on the diagram are grid points with different concentration of pollutants. Each small box on the diagram is a mesh length and it represents distances in kilometres.

The concentration – distance diagram enables us to evaluate our model and it shown with increase in distance along the x and y axes the concentration of any pollutant decrease's simultaneously.

For further mathematical evaluation check appendix 2 for more information.

4.70 LIMITS OF AIR POLLUTANTS DISPERSION MODEL

The air pollutant dispersion model provides a simple method by which useful results can be obtained provided its limitations are properly observed. The model is most accurate for downwind distances between 100 and 2000 meters. For distances below 100 meters, the value of ρ_A (concentration of specie A where a is any pollutant) has to be corrected by considering the details of the wind flow pattern around the source structure. Similarly for distance greater than 2000 meters, the local terrain features such as mountains, vegetation etc and meteorological variable such as rainfall, humidity, radiation, wind speed and direction etc have to be taken into consideration.

The dispersion coefficients (diffusivities); K_{xx} and K_{yy} used in the equation are not very accurate because of approximation. Also, the model neglects the turning point of the wind due to frictional effects. This tends to spread the plume in the cross – wind direction. Also, the consideration of any absorption or deposition of pollutants when the plume reaches the ground is neglected. If the plume is reactive, the model gives inaccurate results. Also the vertical component of air pollutant transport was neglected and any calculation towards that end is impossible.

Hence, care is required in using these modelling equation (10) and the boundary condition (11),

CHAPTER FIVE

5.0 METHODOLOGY OF COMPUTER PROGRAMMING OF AIR POLLUTION DISPERSION MODEL DEVELOPED

The program to solve the second order parabolic partial differential equation meant to describe the diffusion of effluents of industrial gases over an area of 1km^2 from the plume of emission was written in the BASIC Language using the micro soft excel.

First it must be recalled that it is necessary to determine the boundary conditions before any solution to the partial differential equation (PDE) is feasible, since the independent variable are the variables X, Y (spatial in nature) and the spread is considered to be homogenous. The diffusivity constant K_{xx} along the x-axis is equal to the diffusivity constant K_{yy} along the y-axis. The concentration of the pollutants are first calculated along the mesh points on the x and y axes in conformity with the exponential function that determines the concentration along the boundaries.

With these values, and using the finite difference scheme derived by numerical methods, it becomes possible to determine the concentration values at the grid point of the plane of diffusion. The concentration of pollutants at a particular point on the grid may help us to determine safe area of habitation.

5.10 PERSENTATION OF THE COMPUTER PROGRAMME

Q – BASIC PROGRAM: DISPERSAL OF AIR POLLUTANTS

```
5 REM      This section calculates the boundary values of the solution  space.
6 OPEN "O" # 1, " Outfile bas"
10 PRINT " Please enter the value of  $\lambda$ "
20 INPUT  $\lambda$ 
30 PRINT " Please input the value of  $\rho$ "
40 INPUT  $\rho$ 
50 PRINT "Please input the value of the diffusivity constant, K"
60 INPUT K
70 PRINT " Enter the value of the wind speed, U"
75 INPUT U
77 REM we calculate the values of the boundary points
80 PRINT " These are the values along the Y boundary"
81 WRITE #1, "These are the values along the Y axis"
```

```

85 FOR j = 0 to 10
90 C(0, j) = ρ*EXP (- 0.2 *K *j)
100 PRINT C(0,j)
101 WRITE #1, " these are the values along the X axis "
110 NEXT j
120 PRINT " these are the values along the X axis "
121 WRITE #1,"these are the values along the X axis "
130 FOR i=1 To 10
140 C(i,0) = P* Exp(- 0.1 * K *j)
150 PRINT C(i,0)
151 WRITE #1, C(i,0)
160 NEXT i
170 WRITE j = 1 to 9
180 FOR i = 1 to 9
190 C(i+1, j) = ( λ* k/u ) * {C(i, j +1) + (i,j-1) +(1 - 2*λ*k/u)*C(i, j)}
195 PRINT C(i,+1, J)
200 NEXT i
210 NEXT j
220 FOR j = 1 To 9
230 FOR i = 1 To 9
231 WRITE #1, C(i, J)
240 PRINT C(i, j)
250 NEXT i
255 PRINT C(i, j)
260 NEXT j
270 END

```

5.20 SIMULATION OF THE COMPUTER PROGRAMME

The air pollution model developed was written in a simple basic language using the Microsoft excel. After the programme ran, values of the parameters to be determined were inputted into it. This was the basis of the computer simulation carried out on the model. The simulation was performed at distance 100m, 200m

and 300m away from the source of emission to buttress the point that at increasing distance away from the stack the concentration of the pollutant decreases.

Now using the pollutant; Nitrogen oxide produced by industry 3 (united wire products Ltd kaduna) for 1998 as a case study. At 100m away from the source of emission, inputting values of the -parameters i.e. diffusivity with value of $16.4 \times 10^{-6} \text{m}^2/\text{s}$, wind speed at 12m/s, mesh length at 0.5m (a constant) and concentration of $0.02 \text{mg}/\text{m}^3$. We obtain the table 5.20a below

Table 5.20a: concentration of pollutant along x and y – axes 100m away from the source of emission.

CONCENTRATION ON X-axis (mg/m^3)	CONCENTRATION ON Y- axis (mg/m^3)
1.999997×10^{-2}	1.999993×10^{-2}
1.999993×10^{-2}	1.999987×10^{-2}
1.99999×10^{-2}	1.999980×10^{-2}
1.999989×10^{-2}	1.999974×10^{-2}
1.999984×10^{-2}	1.999967×10^{-2}
1.999980×10^{-2}	1.999960×10^{-2}
1.999977×10^{-2}	1.999954×10^{-2}
1.999974×10^{-2}	1.999947×10^{-2}
1.999970×10^{-2}	1.999941×10^{-2}
1.999967×10^{-2}	1.999934×10^{-2}

The disparity in the X and Y values can be attributed to the uneven development and movement of meteorological parameters.

On plotting a graph of this simulated value we obtain the graph in figure 5.20a.

Also, inputting the same value of diffusivity, wind speed, concentration and mesh length into the program but this time around, with a distance 200m away from the source of emission, we obtain the table 5.20b below

Table 5.20b: Concentration of pollutant along x – and y –axes 200m away from the stack.

CONCENTRATION ON X- axis (mg/m ³)	CONCENTRATION ON Y-axis (mg/m ³)
1.999998 x 10 ⁻²	1.999974 x 10 ⁻²
1.999996 x 10 ⁻²	1.999947 x 10 ⁻²
1.999941 x 10 ⁻²	1.9999921 x 10 ⁻²
1.999921 x 10 ⁻²	1.999895 x 10 ⁻²
1.999901 x 10 ⁻²	1.999869 x 10 ⁻²
1.999882 x 10 ⁻²	1.999842 x 10 ⁻²
1.999862 x 10 ⁻²	1.999816 x 10 ⁻²
1.999842 x 10 ⁻²	1.99979 x 10 ⁻²
1.999823 x 10 ⁻²	1.999764 x 10 ⁻²
1.999803 x 10 ⁻²	1.999737 x 10 ⁻²

On plotting these simulated values on a graph we obtain the graph in figure 5.20b.

In the same way, inputting the same values of diffusivity, wind speed, mesh length and concentration into the program, using a distance of 300m away from the source of emission we obtain a dispersion graph similar to that in figure 5.20a and 5.20b. But first, the table will take the outlook in table 5.20c.

Table 5.20c: Concentration of pollutant along x – and y –axes 300m away from the source of emission

CONCENTRATION ON X-axis (mg/m ³)	CONCENTRATION ON Y– axis (mg/m ³)
1.999974 x 10 ⁻²	1.999967 x 10 ⁻²
1.999947 x 10 ⁻²	1.999934 x 10 ⁻²
1.999921 x 10 ⁻²	1.999901 x 10 ⁻²
1.999895 x 10 ⁻²	1.999869 x 10 ⁻²
1.999869 x 10 ⁻²	1.999836 x 10 ⁻²
1.999842 x 10 ⁻²	1.999836 x 10 ⁻²
1.999842 x 10 ⁻²	1.999803 x 10 ⁻²
1.999816 x 10 ⁻²	1.999777 x 10 ⁻²
1.99979 x 10 ⁻²	1.999737 x 10 ⁻²
1.999764 x 10 ⁻²	1.999704 x 10 ⁻²
1.999737 x 10 ⁻²	1.999672 x 10 ⁻²

FIGURE 6.20a: GRAPH OF CONCENTRATION OF POLLUTANT ALONG Y-AXIS AGAINST X-AXIS 100M AWAY FROM STACK

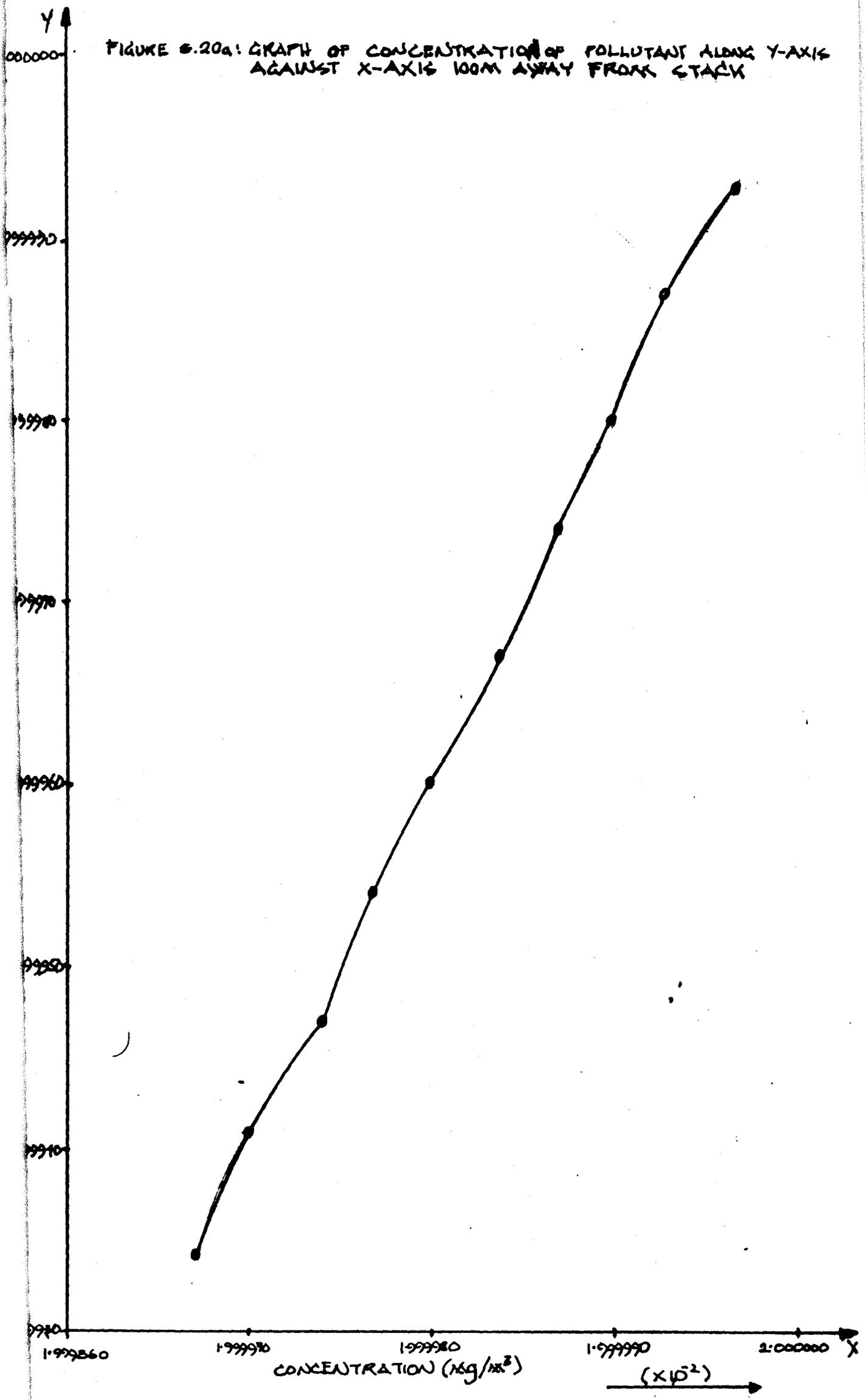


FIGURE 5.206: GRAPH OF CONCENTRATION OF POLLUTANT ALONG Y-AXIS AGAINST X-AXIS 200m AWAY FROM STACK

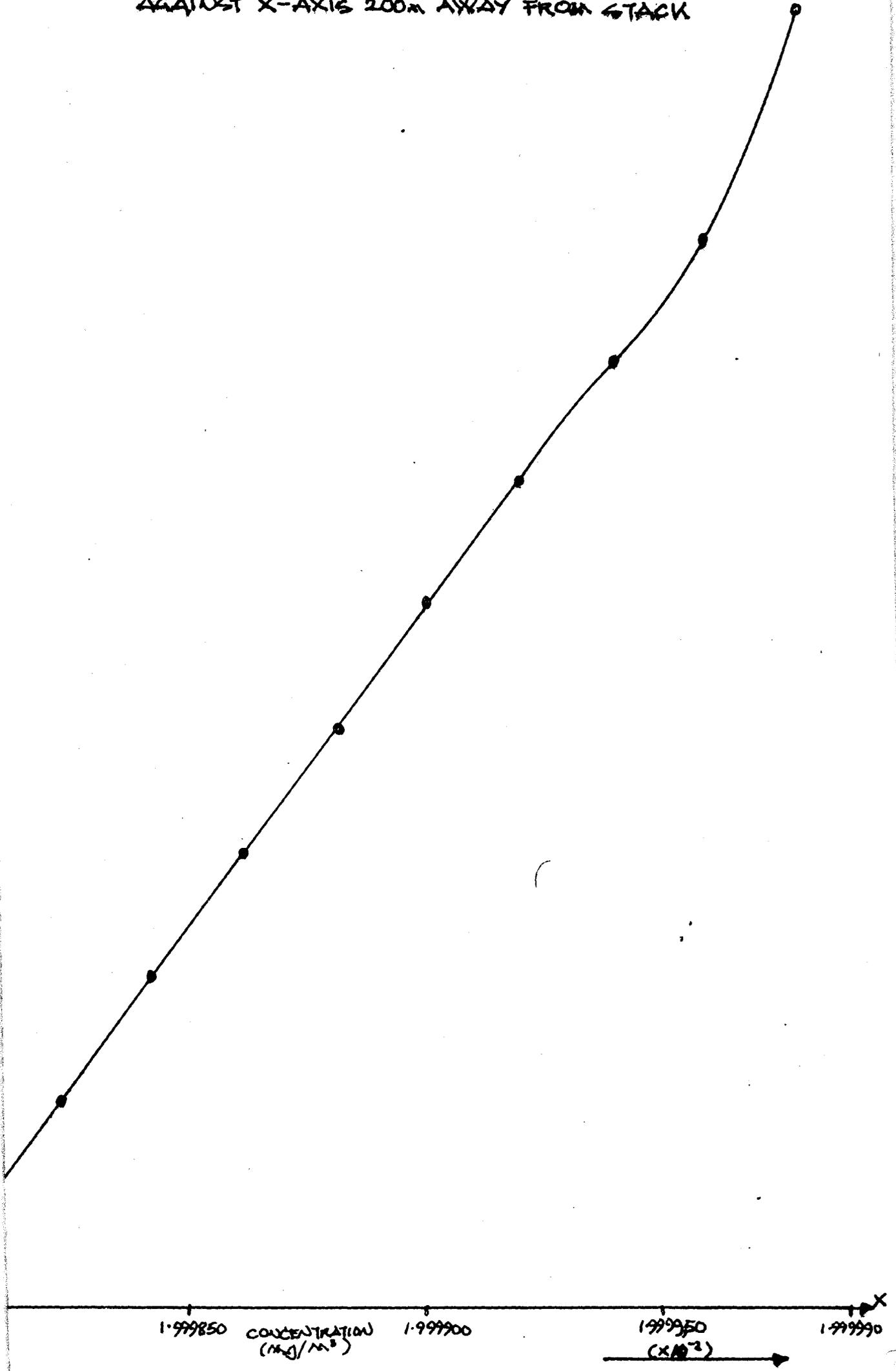


FIGURE 5.20C: GRAPH OF CONCENTRATION OF POLLUTANT ALONG Y-AXIS AGAINST X-AXIS 300M AWAY FROM STACK

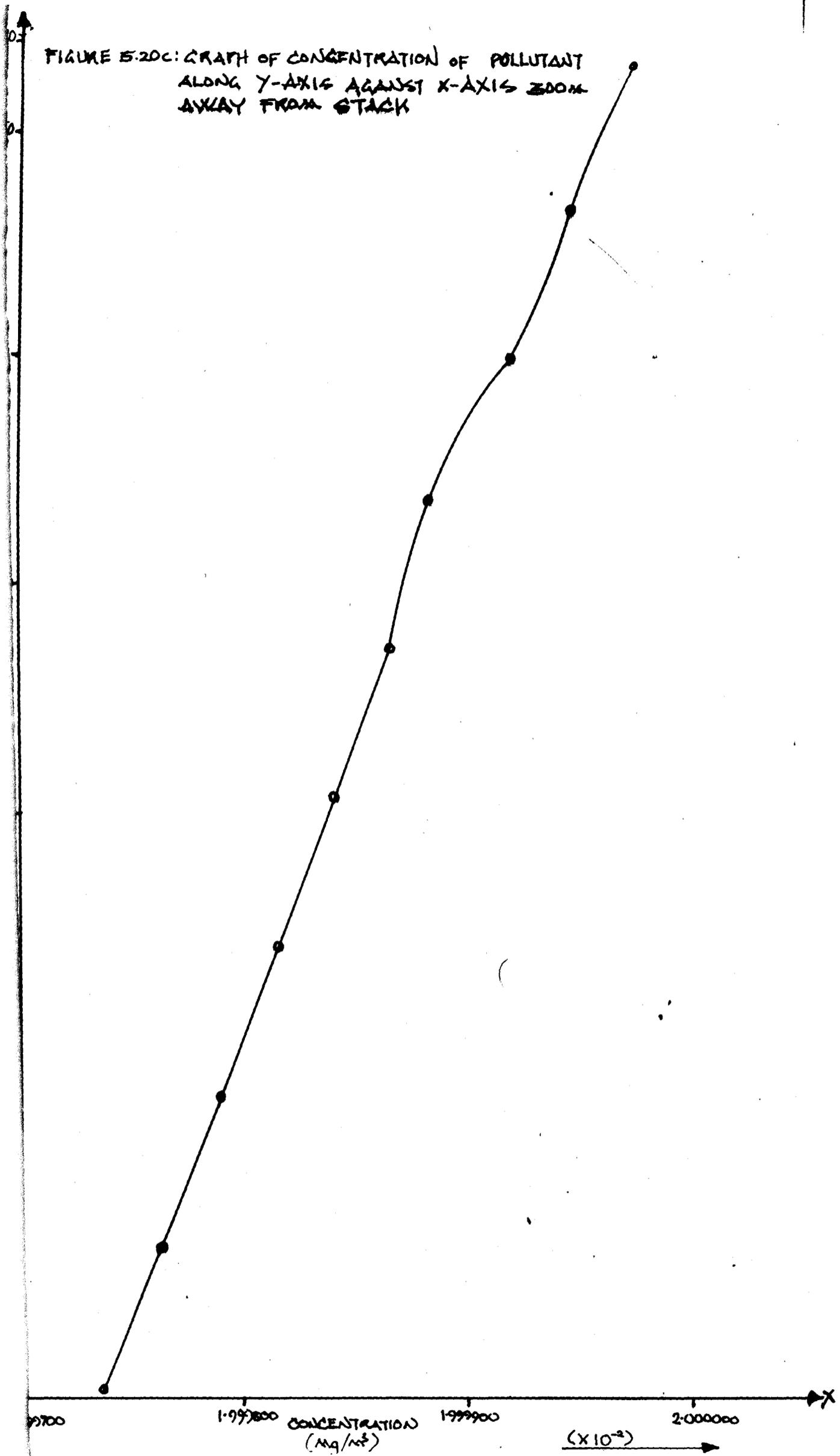
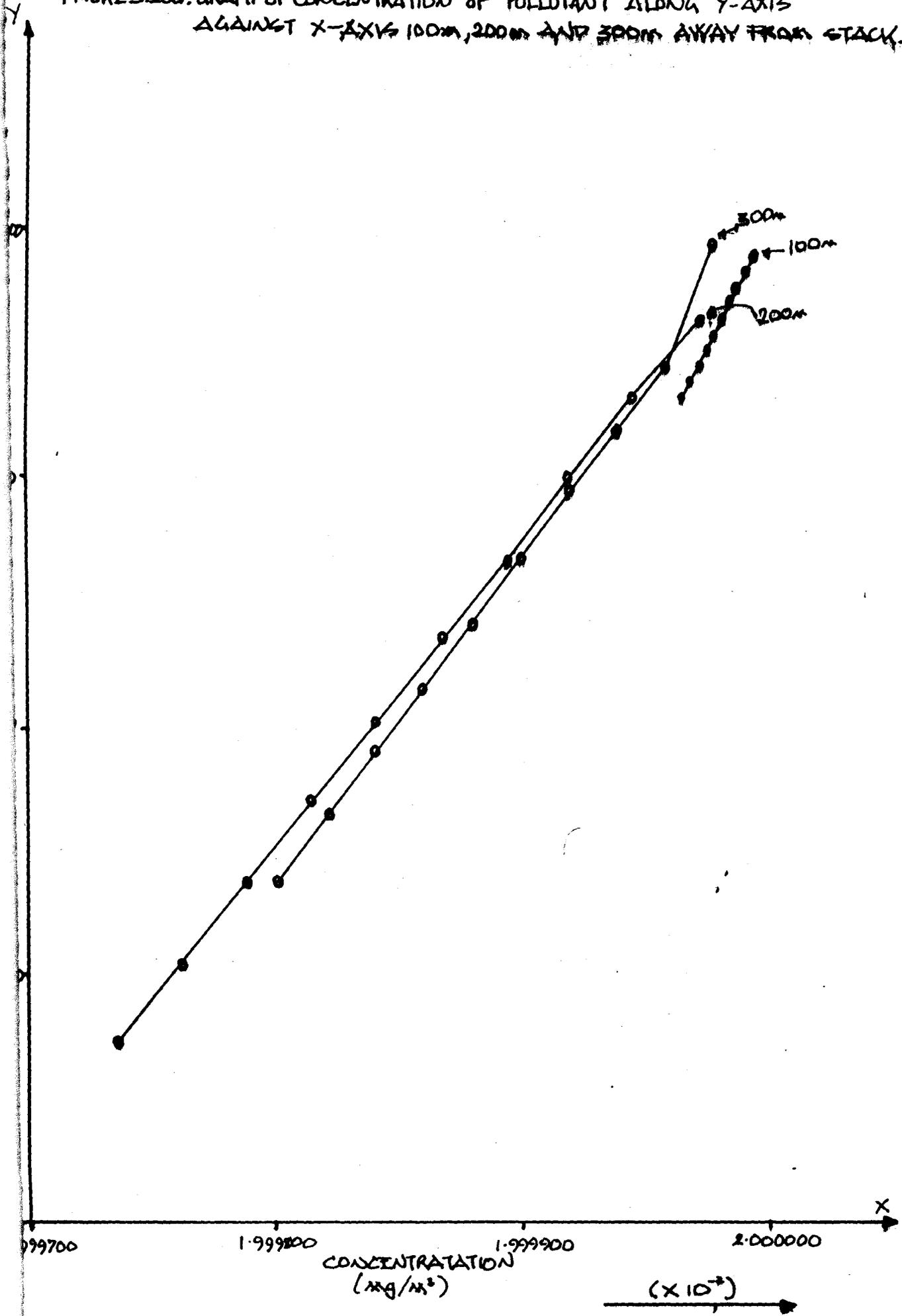


FIGURE 5.20d: GRAPH OF CONCENTRATION OF POLLUTANT ALONG Y-AXIS AGAINST X-AXIS 100m, 200m AND 300m AWAY FROM STACK.



On plotting a graph of these simulated values, it takes the shape of the previous graphs and it is shown on figure 5.20c.

Finally using the simulated values of Table 5.20(a-c) to plot out a graph showing dispersions we obtain a superimposed graph of figure 5.20(a-c) and this is represented in figure 5.20d.

5.30 DISCUSSION OF THE COMPUTER SIMULATED RESULT

The computer-simulated result shows the same trend/pattern, they indicate that with increasing distance the pollutant concentration from the source of emission decreased. This shows an inverse relation between the distance and the pollutant concentrations. A typical example of this is shown in Table 5.20a, where the emitted oxide of nitrogen has an initial concentration of $2 \times 10^{-2} \text{ mgm}^3$ but on dispersion by wind and other meteorological factor, it reduced to 1.999934×10^{-2} and 1.99967×10^{-2} at 100m (on the y – and x –axis respectively). This same trend were seen in table 5.20b and 5.20c that shows how the concentration decreased 200m and 300m respectively away from the source of emission.

The graphical representation also showed a decrease in concentration of pollutants with respect to distance. The graphs in figures 5.20(a-d) show a dispersion pattern, which correspond to the model. In figure 5.20d the dispersion is more evident in that at higher distance it gives a higher dispersion hence a wider spread. With this result we can deduce that the simulated results showed or agreed with the dispersion model. Concluding that the model actually shows how concentration reduces with increasing distance, therefore, confirming the validity of the dispersion model.

CHAPTER SIX

6.00 A CASE STUDY OF AIR POLLUTION TRENDS IN KADUNA INDUSTRIAL AREA

The data overleaf shows the major air pollutants emitted from nine industries located within the Kaduna South Industrial Area for the past three years i.e. 1996 to 1998. These data shows the amount of pollutants released into the atmosphere as against the Federal Environmental Protection Agency Limits. The limits here serve as a form of control. It is pegged to limit the amount of pollutants emitted by these industries into the surrounding environment. The individual industry is expected to conform to these limits for different pollutant they emit. From here we can say that FEPA limit is a control on amount or concentration of pollutant emitted in order to reduce or check hazards on health and environment as the case may be.

From the data it can be seen that the major source of air pollutants emitting from these industries are oxides of nitrogen, sulphur dioxides, carbon dioxides, carbon monoxides, hydrocarbons, ammonia, and particulate matters. The data also shows that the concentration of air pollutants emitted from some industries for some years exceeded that of the FEPA limits; that means these industries are not keeping strictly to FEPA regulation on the control of emitted pollutant.

6.10 RESULTS OF AIR POLLUTION DATA OF INDUSTRIES IN KADUNA INDUSTRIAL AREA

The results obtained from air quality samples as collected from Kaduna South Industrial Area from 1996-1998 are as presented in tables 6.10(a-b) below: The graphical presentations of these tables 6.10(a-b) are as shown in figure 6.10(a-d) to clearly analyse these results. The pollutants shown on these graphs are oxides of nitrogen, sulphur dioxide, carbon (iv) oxide and particulate matters.

6.20 DISCUSSION OF THE GRAPHICAL REPRESENTATION OF AIR POLLUTION AS AGAINST FEPA LIMIT

The graphical representations of figures 6.10 (a-d) are those of the major air pollutants inherent in the kaduna South industrial area as against FEPA regulation limits. These major air pollutants include sulphur dioxide (SO₂), carbon monoxide (CO), oxides of nitrogen (NO₂), and total particulate matter.

PARAMETERS	FEPA LIMIT (mg/m ³)	FINETEX TEXTILE PLC KADUNA			PEUGEOT AUTOMOBILE NIG LTD. KADUNA			UNITED WIRE PRDTS. LTD. KADUNA			SAFA FOAM NIG LTD KAD			NIG BOTTLING CO (NBC) PLC. KADUNA		WEST AFR BITUMEN & EMUL. CO. (WABECO)			
		1996	1997	1998	1996	1997	1998	1996	1997	1998	1996	1997	1998	1996	1998	1996	1997	1998	1998
		Total Particulate	0.250	0.321	0.33	0.341		ND			ND					0.37	0.3		
Nitrogen Oxide, Nox	0.062-0.093	0.0614	0.06	0.067	0.004	0.005	0.003	0.013	0.026	0.02	0.003	0.002	0.006	0.04	0.04	0.0085	0.009	0.033	0.033
Sulphur (iv) Oxide, SO ₂	0.026	0.034	0.04	0.03	0.009	0.008	0.012	0.02	0.021	0.02	0.005	0.005	0.005	0.04	0.05	0.026	0.026	0.025	0.025
Carbon(iv) Oxide, CO ₂	NS	2.878	3.0	0.045	803	811	817	1831	1833	1844	843	845	850.5	0.43	0.46	1910.5	1919	1924	1924
Carbon (ii) Oxide, CO	11.43	0.5	0.45	3.25	4.22	4.55	4.78	6.05	5.97	6.11	3.85	4.05	5.5	0.04	0.04	5.94	5.99	6.05	6.05
Ozone, O ₃	0.1-0.2	0.019	0.021	0.023		ND			ND					ND	ND				
Ammonia, NH ₃	0.02	0.111	0.067	0.016		ND			ND					0.01	0.02				
Hydrocarbons	0.16	ND	ND	ND		ND			ND					0.01	0.02				
Dust	0.6		ND			ND			ND					ND	ND				

Note:

NS-Not stated

ND-Not detected

TABLE 6.00b ANALYSIS OF AIR QUALITY COLLECTED FOR INDUSTRY IN KADUNA

INDUSTRY 7			INDUSTRY 8			INDUSTRY 9		
SEVEN UP BOTTLING COMPANY KADUNA			TOWER GALVANISED PRODS.LTD., KADUNA			VULCAN GASES NIG LTD., KADUNA		
1996	1997	1998	1996	1997	1998	1996	1997	1998
			0.23	0.25	0.28	0.114	0.36	0.285
0.023	0.024	0.03	0.028	0.01	0.018	0.05	0.06	0.062
0.058	0.062	0.065				0.139	0.14	0.146
46,616	1607.0	1,641	171	177	180.3	2.71	2.77	0.289
13.1	12.1	9.2	7.7	7.72	7.74	0.39	0.39	0.4
						0.03	0.03	0.033
						0.043	0.04	0.046
						ND	ND	ND
			0.3	0.32	0.36		ND	

NS-Not stated

ND-Not detected

FIGURE 6.10a: GRAPHICAL REPRESENTATION OF SULPHUR DIOXIDE (SO₂) EMMITED INTO THE ATMOSPHERE.

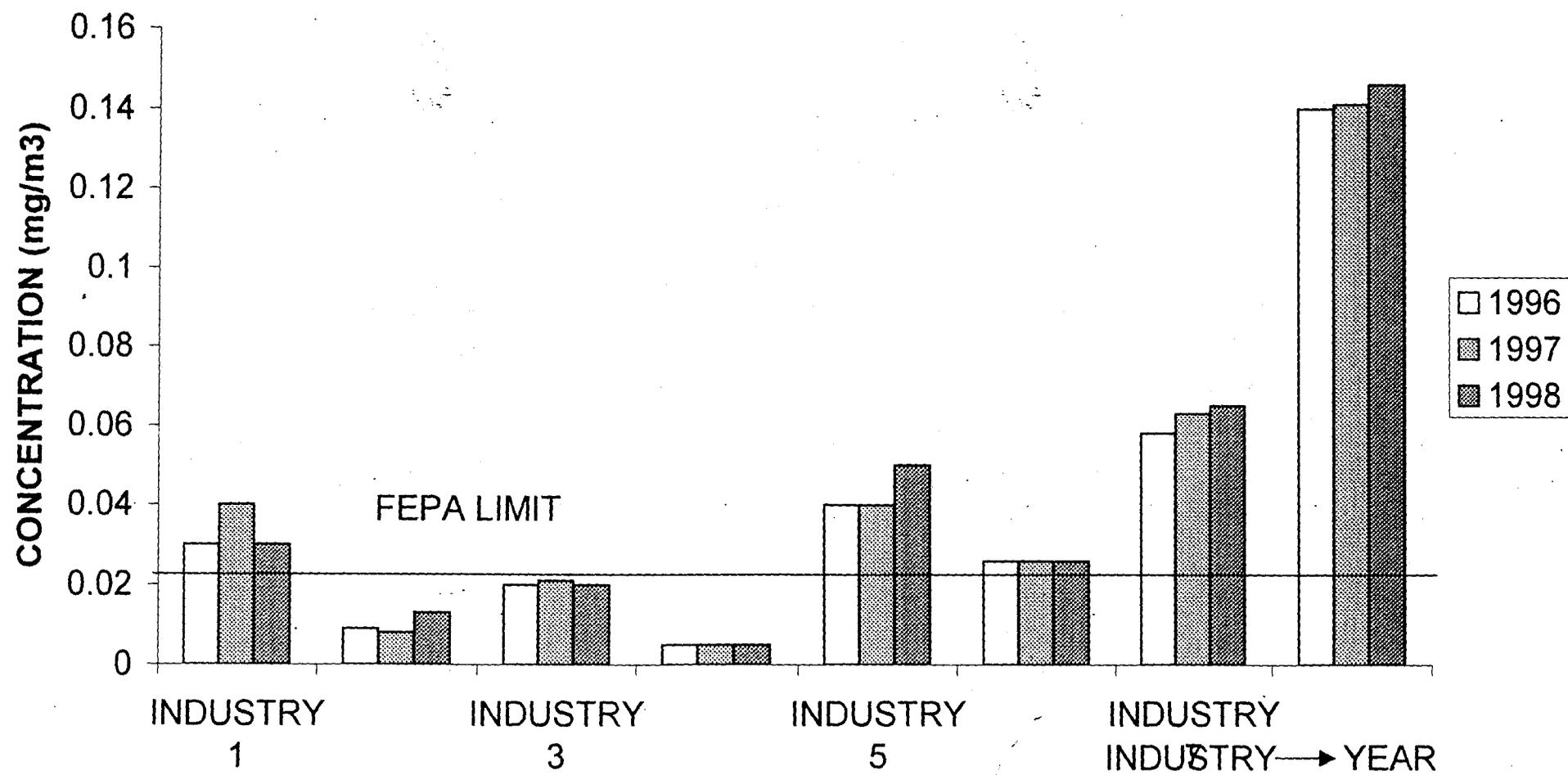


FIGURE 6.10b: GRAPHICAL REPRESENTATION OF CARBON MONOXIDE(CO) EMMITED INTO THE ATMOSPHERE.

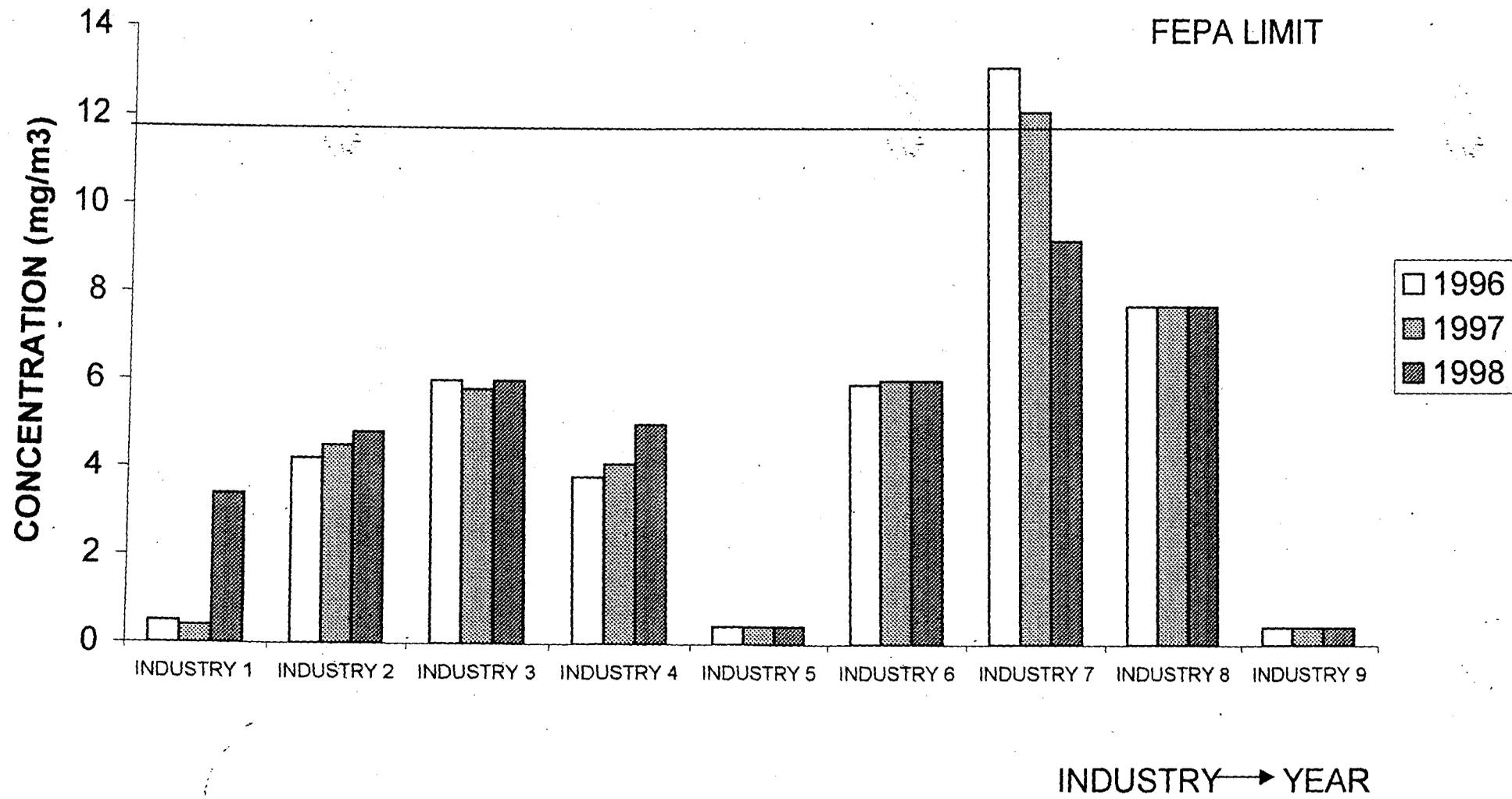


FIGURE 6.10c: GRAPHICAL REPRESENTATION OF OXIDE OF NITROGEN(NO_x) EMMITED INTO THE ATMOSPHERE.

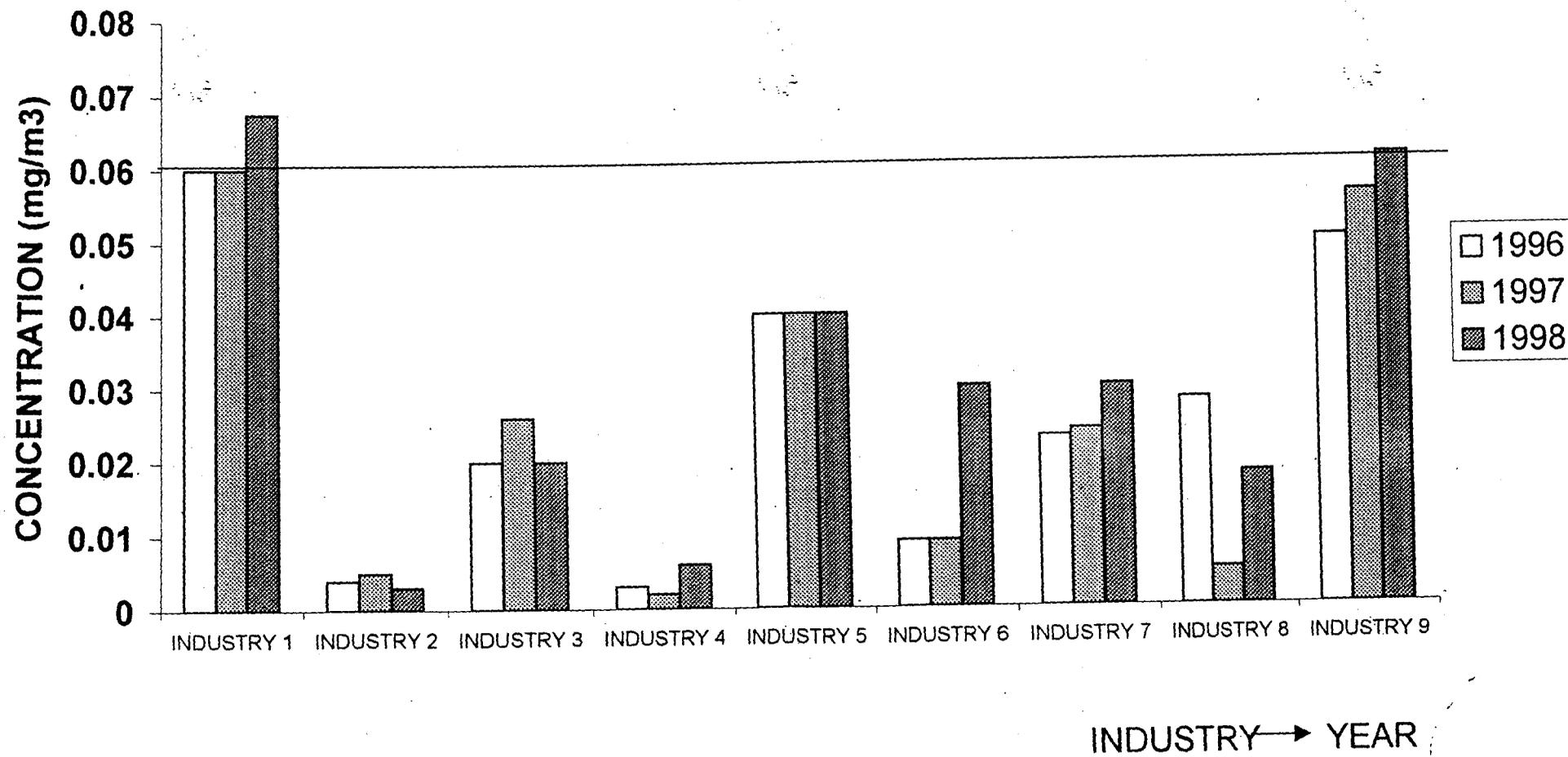
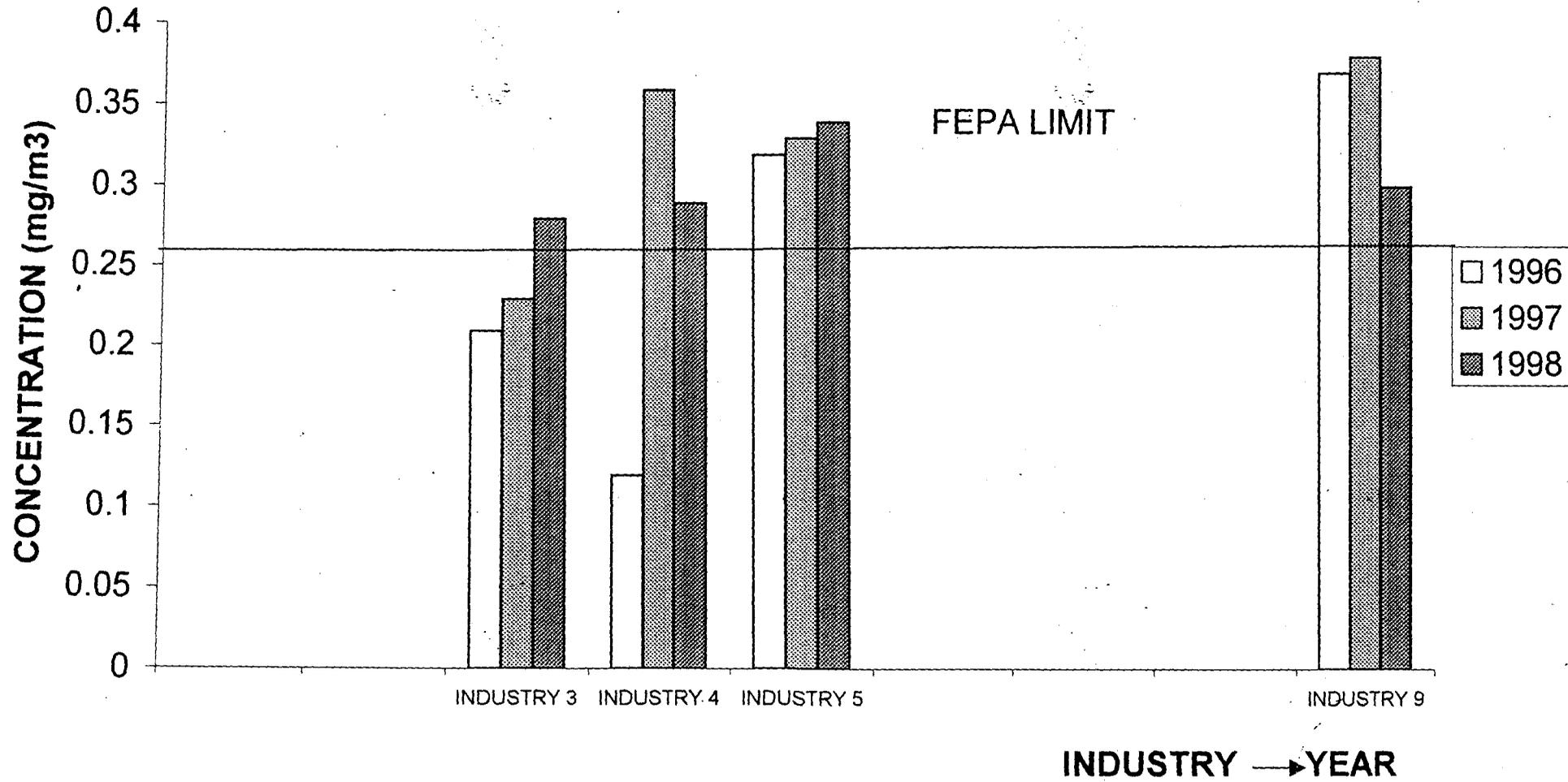


FIGURE 6.10d: GRAPHICAL REPRESENTATION OF TOTAL PARTICULATE MATTER EMMITED INTO THE ATMOSPHERE.



For the first graphical representation (figure 6.10a), i.e. the sulphur dioxide graph, it can be seen that the concentration of sulphur dioxide emitted was against the industries and years. The drawing of the horizontal line to the industries and years co-ordinate (ordinate) parallel to industries and years co-ordinate (abscissa) is to indicate the FEPA regulation limit. It should be observed that four industries (1,5,7 and 9) of the eight industries that emits SO₂ exceeds the FEPA regulation limit in the concentration of SO₂ released into the atmosphere. Also industry 7 is emitting at just the FEPA regulation limit for the three years under study. For these four industries indicate by the graph it can be seen that the FEPA regulation limit of 0.26mg/m³ was exceeded for these years. This maybe as a result of the raw materials used in production processes in these industries and also the absence of appropriate SO₂ control equipment. Particularly worrying is that of industry a which shows a repeated trend of high SO₂ emission into the atmosphere.

Industry 8 showed no emission of SO₂ into the atmosphere the FEPA industries 2 and 3 which emits below the FEPA regulation limits show an increasing trend of SO₂ emission which when higher production level favours them will not likely exceed that of FEPA regulation limit.

For the second graphical representation (figure 6.10b), i.e. carbon monoxide (CO) emitted plotted against industries and years. The deviations were very minimal as against the FEPA regulation limit of 11.43mg/m³. The only industry that exceeds the limit was industry 7 for the years 1996 and 1997 but below the limit in 1998. The lowering of the emission of CO to the atmosphere in 1998 maybe as a result of control check by the regulation body in this case KEPA (Kaduna Environmental Protection Agency), or as a result of the use a new raw material which doesn't emit so much CO, or the presence of efficient CO control equipment in the industry. The highest emission level for industry 7 was 13.10 mg/m³ in the year 1996.

Though industries (1,2,3,4,5,8, and 9) did not exceed that of the regulation limit but industries (1,2,3,4,6, and 8) showed an increasing trend emission of CO which must be checked to prevent them from exceeding the regulation limit.

For the third graphical representation (figure 6.10c), i.e. oxide of nitrogen (NO_x) emitted plotted against industries and years. The deviations were very minimal as against the FEPA regulation limit of 0.062mg/m³. It can be seen that the only industry that exceeded the limit was industry 1 for the year 1998 with an emission level of 0.067mg/m³.

Though industry 9 did not exceed the limit. A bad trend for industry 9 was observed because it showed an increasing trend of NO_x emission with the increasing years. Also industries 3,5,6, and 7 showed a trend of increasing NO_x emission even

though below the limit this also should be checked. Though industry 8 did not exceed the limit but it showed no even pattern of NO_x emission into the atmosphere.

For the fourth graphical representation (figure 6.10d), i.e. total particulate matter emitted plotted against industries and year. The deviation were quite high as against the FEPA of $0.25\text{mg}/\text{m}^3$. It can be seen that industries 3,4,5, and 9 exceeded the limit with industry 9 showing the highest emission level of $0.38\text{mg}/\text{m}^3$ in 1997. While industry 3 exceeded the limit once in 1998, industry 4 exceeded the limit twice in the years 1997 and 1998 and industries 5 and 9 repeatedly showed increment in the three years understudy. Again industries 3 and 5 showed a consistent increase in particulate matter emission into the atmosphere but industries 4 and 9 matter an inconsistent increase; this maybe as a result of the use of inconsistent or changing raw materials or there exist disruptions in the production rate arbitrarily. This is a very bad trend, which must be checked so as to have a consistent particulate emission level that can be easily analyzed and controlled subsequently.

Industries 1,2,6,7,and 8, showed no emission of particulate matter into the atmosphere; this maybe as a result of the raw material used in production not emits it.

6.21 DISCUSSION OF THE GRAPHICAL REPRESENTATION OF AIR POLLUTION AS AGAINST FEPA LIMIT

The graphical representations of figures 6.10 (a-d) are those of the major air pollutants inherent in the kaduna South industrial area as against FEPA regulation limits. These major air pollutants include sulphur dioxide (SO_2), carbon monoxide (CO), oxides of nitrogen (NO_2), and total particulate matter.

For the first graphical representation (figure 6.10a), i.e. the sulphur dioxide graph, it can be seen that the concentration of sulphur dioxide emitted was against the industries and years. The drawing of the horizontal line to the industries and years co-ordinate (ordinate) parallel to industries and years co-ordinate (abscissa) is to indicate the FEPA regulation limit. It should be observed that four industries (1,5,7 and 9) of the eight industries that emits SO_2 exceeds the FEPA regulation limit in the concentration of SO_2 released into the atmosphere. Also industry 7 is emitting at just the FEPA regulation limit for the three years under study. For these four industries indicate by the graph it can be seen that the FEPA regulation limit of $0.26\text{mg}/\text{m}^3$ was exceeded for these years. This maybe as a result of the raw materials used in production processes in these industries and also the absence of appropriate SO_2 control equipment. Particularly worrying is that of industry a which shows a repeated trend of high SO_2 emission into the atmosphere.

Industry 8 showed no emission of SO₂ into the atmosphere the FEPA industries 2 and 3 which emits below the FEPA regulation limits show an increasing trend of SO₂ emission which when higher production level favours them will not likely exceed that of FEPA regulation limit.

For the second graphical representation (figure 6.10b), i.e. carbon monoxide (CO) emitted plotted against industries and years. The deviations were very minimal as against the FEPA regulation limit of 11.43mg/m³. The only industry that exceeds the limit was industry 7 for the years 1996 and 1997 but below the limit in 1998. The lowering of the emission of CO to the atmosphere in 1998 maybe as a result of control check by the regulation body in this case KEPA (Kaduna Environmental Protection Agency), or as a result of the use a new raw material which doesn't emit so much CO, or the presence of efficient CO control equipment in the industry. The highest emission level for industry 7 was 13.10 mg/m³ in the year 1996.

Though industries (1,2,3,4,5,8, and 9) did not exceed that of the regulation limit but industries (1,2,3,4,6, and 8) showed an increasing trend emission of CO which must be checked to prevent them from exceeding the regulation limit.

For the third graphical representation (figure 6.10c), i.e. oxide of nitrogen (NO_x) emitted plotted against industries and years. The deviations were very minimal as against the FEPA regulation limit of 0.062mg/m³. It can be seen that the only industry that exceeded the limit was industry 1 for the year 1998 with an emission level of 0.067mg/m³.

Though industry 9 did not exceed the limit. A bad trend for industry 9 was observed because it showed an increasing trend of NO_x emission with the increasing years. Also industries 3,5,6, and 7 showed a trend of increasing NO_x emission even though below the limit this also should be checked. Though industry 8 did not exceed the limit but it showed no even pattern of NO_x emission into the atmosphere.

For the fourth graphical representation (figure 6.10d), i.e. total particulate matter emitted plotted against industries and year. The deviation were quite high as against the FEPA of 0.25mg/m³. It can be seen that industries 3,4,5, and 9 exceeded the limit with industry 9 showing the highest emission level of 0.38mg/m³ in 1997. While industry 3 exceeded the limit once in 1998, industry 4 exceeded the limit twice in the years 1997 and 1998 and industries 5 and 9 repeatedly showed increment in the three years understudy. Again industries 3 and 5 showed a consistent increase in particulate matter emission into the atmosphere but industries 4 and 9 matter an inconsistent increase; this maybe as a result of the use of inconsistent or changing raw materials or there exist disruptions in the production rate arbitrarily. This is a very bad trend, which must be

checked so as to have a consistent particulate emission level that can be easily analyzed and controlled subsequently.

Industries 1,2,6,7,and 8, showed no emission of particulate matter into the atmosphere; this maybe as a result of the raw material used in production not emits it.

CHAPTER SEVEN

7.00 CONCLUSION AND RECOMMENDATION

As stated earlier in the literature review aspect of this project; the hazardous toll of air pollution to human health and the environment cannot be over emphasized. Coupled with the fact these pollutants are easily dispersed by wind and other meteorological parameters to the immediate environment. Therefore, care has to be taken to curb the detrimental effects a prolong exposure can cause. Though some equipment have been developed to control this pollution more is still needed to effectively control the emission of air pollution. Hence with development of a typical air pollution dispersion model in this research project which predicts the rate at which emitted concentration of pollution various with distances another forms of as control has been discovered.

From here one can recommend that this air dispersion model can be used to design an effective air pollution control equipment which controls emission of the pollutants from the source. But in carrying out any design, care should be taken to adequately consider the few limitations inherent in this dispersion model.

7.10 CONCLUSION

From the results of the dispersion model investigated, the aims of this research work were to a very large extent achieved. The model can be used in predicting the amount of air pollutants emitted into the surrounding environment with respect to distances from the point of emission.

The model actually showed the trend in the reduction of the pollutant concentration with increasing distance; this confirms and supports the validity and authenticity of this dispersion model. It can be used to effectively determine the safe distance for human habitation from an industrial area with knowledge of tolerant emission limit from the pollution regulation body (FEPA). (Therefore, the model can be used in controlling the emission of air pollutants from any industrial area to any industrial city.)

Finally and conclusively to say the least without mincing words, this has been the greatest achievement of this dispersion model.

Again, during the course of this research work the conformity and non-conformity of some industries to standard FEPA regulation limits for some major air pollutant was studied and appropriate control measures prescribed where necessary.

7.20 RECOMMENDATION

Since Nigeria, like any other developing country is striving towards bettering the lots of its teeming citizens and this can to a very much extent be achieved through technological growth of its industries or industrial base. Hence the development of new industries cannot be ruled out completely. In trying to strike a balance between safety (i.e. to human health and the environment) and industrial growth, new industries should be zoned to be far away from possible residential areas, i.e. the zoning of the industries and residences should be taken into cognisance before their actual development or creation.

Also the pollution of regulating body (i.e. the new Federal Ministry of Environment) should take it as a God assigned patriotic duty to make sure that these industries that emits these pollutants adhere strictly to the recommended regulation limits.

Again, industries which uses raw materials that emits so much pollutants should change the raw materials they use as their source of production or they should use modified equipment or processes so as to check these emissions of hazardous pollutants.

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APPENDIX 1

1.0 CALCULATION OF DIFFUSIVITY OF GASEOUS POLLUTANTS

To estimate the diffusivity of SO₂ in the atmospheric air at atmospheric pressure and at 25°C.

Solution:

Diffusion volumes from table 4.50a₁ for SO₂ = 41.1

Diffusion volumes from table 4.50a₁ for Air = 20.1

1 standard atmosphere = 1.013 bar

Molecular weight of SO₂ = 64

Molecular weight of Air = 29

Applying the equation developed by Fuller et al (1966), we have

$$K_v = 1.013 \times 10^{-7} T^{1.75} \left(\frac{1}{M_a} + \frac{1}{M_b} \right)$$

$$\frac{P \left((\sum_a V_i)^{1/3} + (\sum_b V_i)^{1/3} \right)^2}{}$$

Where K_v = diffusivity, m²/s

T = temperature, k

M_a, M_b = Molecular weights of components a and b

P = Total pressure, bar

$\sum_a V_i, \sum_b V_i$

a b = the summation of the special diffusion volume coefficients for components a and b, given in table 4.50a of Chapter Four.

$$\text{Therefore, } K_v = 1.013 \times 10^{-7} \times 298^{1.75} \left(\frac{1}{64} + \frac{1}{29} \right)$$

$$\frac{1.013 (41.1)^{1/3} + (20.1)^{1/3}}{}$$

$$= \frac{4.8466 \times 10^{-4}}{38.563}$$

$$K_v = 12.6 \times 10^{-6} \text{ m}^2/\text{s}.$$

1.1 To estimate the diffusivity of N₂O in the air at atmospheric pressure and at 25°C

Using the boundary equation formula

$$\rho_{j+1}^i = P_o e^{-xK_{xx}}$$

Where

$$\rho_o = 0.04, K_{xx} = 12.6 \times 10^{-6} \text{m}^2/\text{s}$$

At point $i=0, j=0$ therefore $x=0$ and $y=0$

$$\rho_{j+1}^i = \rho_o^i = 0.04 e^{-0(12.6 \times 10^{-6})}$$

$$= 0.04 \times 1$$

$$\rho_o^1 = 0.04$$

From this calculation, it can be deduced that the stack concentration is 0.04 g/m^3 at point $x=0, y=0$.

Now let's consider 100 metres away from the stack.

At point $x=0.1\text{km}$ and $y=0$, i.e., $j=0, i=1$

$$\rho = \rho_1^i = \rho_o e^{-xK_{xx}}$$

$$= 0.04 e^{-0.1(12.6 \times 10^{-6})}$$

$$\rho_1^i = 0.03999 \text{ mg/m}^3$$

This value shows that at 100m away from the source of emission SO_2 has a reduced concentration of 0.03999 approximately.

Again, taking $x=0.1\text{km}$ and $y=0.2\text{km}$

$$\text{The area of emission} = 0.1 \times 0.2 = 0.02\text{km}^2$$

Using the modeling formula:

$$\rho_j^{i+1} = \frac{\lambda K_{xx}}{\bar{U}} \left(\rho_{j+1}^i + \rho_{j-1}^i \right) + \left(1 - \frac{2\lambda K_{xx}}{\bar{U}} \right) \rho_j^i$$

Where $i=1$ and $j=1$

$$\therefore \rho_1^2 = \frac{\lambda K_{xx}}{\bar{U}} \left(\rho_2^1 + \rho_0^1 \right) + \left(1 - \frac{2\lambda K_{xx}}{\bar{U}} \right) \rho_1^1$$

From the previous calculation $\rho_o^1 = 0.04\text{g/m}^3$

$$\rho_2^1 = \rho_j^{i+1}, \text{ where } i=0, j=2$$

$$\rho_2^1 = \rho_o e^{-yK_{yy}}$$

Solution:

Diffusion volumes from table 4.50a for $N_2O = 35.9$

Diffusion volumes for air = 20.1

Standard atmosphere = 1.013 bar

Molecular weight of $N_2O = 44$

Molecular weight of Air = 29

$$\begin{aligned} \text{Therefore, } K_v &= 1.013 \times 10^{-7} \times 298^{1.75} \left(\frac{1}{64} + \frac{1}{29} \right) \\ &= \frac{1.013((35.9)^{1/3} + (20.1)^{1/3})^2}{36.68} \\ &= 5.179 \times 10^{-4} \end{aligned}$$

$$K_v = 14.1 \times 10^{-6} \text{ m}^2/\text{s}$$

The same pattern was followed in calculating the diffusivity of other gaseous pollutants as tabulated in table 4.50b.

APPENDIX 2

2.0 CALCULATION OF CONCENTRATIONS USING THE MODELLING FORMULAE DEVELOPED.

To perform this task, we use the boundary condition formula and the modeling formula which are

$$P = \rho_{j+1}^i = P_o e^{-xK_{xx}} \text{ and}$$

$$\rho_j^{i+1} = \frac{\lambda K_{xx}}{\bar{U}} \left(\rho_{j+1}^i + \rho_{j-1}^i \right) + \left(1 - \frac{2\lambda K_{xx}}{\bar{U}} \right) \rho_j^i$$

Where P = Concentration of the gaseous pollutant

K_{xx} = Diffusivity of the gaseous pollutant

\bar{U} = Velocity of the wind

X = ratio of the mesh lengths along the x – axis and the y – axis respectively.

For stability as in our case it has a constant value of 0.5.

Consider SO_2 being emitted into the atmosphere by NBC in 1997 at a distance of $x = 0\text{km}$ and $Y = 0\text{km}$, i.e. at the stack.

$$= 0.04e^{-0.04(12.6 \times 10^{-6})}$$

$$= 0.039999899$$

$$\rho_2^1 \approx 0.03999 \text{ mg/m}^3$$

For November, 1996 wind speed = 5.4 knots

Where 1 knot = 2m/s

$$\begin{aligned} \text{Wind speed} &= 2 \times 5.4 \\ &= 10.8 \text{ m/s} \end{aligned}$$

Now substituting the values of \bar{U} , ρ^1 , ρ_0^1 and ρ_1^1 into (1)

We have:

$$\begin{aligned} \rho_2^1 &= \frac{0.5 \times 12.6 \times 10^{-6}}{10.8} (0.03999 + 0.04) + \left(1 - \frac{2 \times 0.5 \times 12.6 \times 10^{-6}}{10.8}\right) 0.03999 \\ &= 4.6661 \times 10^{-7} + 3.7 \times 10^{-3} \end{aligned}$$

$$\rho_1^2 = 3.7 \times 10^{-3} \text{ mg/m}^3$$

= 0.0037 mg/m³ of SO₂ at 100m along x – axis and 200m along y – axis

away from the source of pollution.

This shows an appreciable decrease in concentration from the initial concentration of 0.04 mg/m³.

APPENDIX 3**DEPARTMENT METEOROLOGICAL SERVICES, NIGERIA****MET. 152/2****VALUE OF MONTHLY AND ANNUAL MEANS AT KADUNA STATION****(Revised 1978)**

MONTHLY MEANS

METEOROLOGICAL ELEMENT	JAN	FEB.	MARCH	APRIL	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.	YEARLY MEAN	YEAR
TEMPERATURE (°c)	23.5	24.4	29.0	29.0	26.9	25.4	24.3	24.0	24.7	25.8	24.5	24.2	25.5	1995
	24.5	27.0	29.2	29.5	26.8	24.7	24.2	23.7	24.1	24.5	23.0	23.3	25.4	1996
	23.9	22.9	27.6	28.0	26.3	25.3	24.4	24.4	24.5	25.7	25.1	23.0	25.1	1997
	22.4	24.8	27.6	29.8	27.3	24.4	24.6	24.3	24.6	24.8	25.1	23.4	25.3	1998
WIND SPEED (knots)	6.7	6.8	5.0	5.0	4.2	5.5	4.0	3.3	3.4	2.7	5.5	5.6	4.8	1995
	5.1	4.6	4.3	4.0	4.7	4.6	4.9	3.4	3.4	3.7	3.6	5.4	4.4	1996
	5.9	10.0	7.2	5.4	4.2	4.4	4.8	3.8	3.1	4.4	2.8	2.8	5.0	1997
	6.8	10.0	7.2	5.4	5.6	5.6	4.8	4.8	4.7	4.8	5.4	5.6	6.0	1998

Note:- Windspeed in Knots

1 Knot = 2 metres/sec.