EVALUATION OF GROUND LEVEL CONCENTRATION

OF POLLUTANT DISPERSION DUE TO GAS FLARING

(A CASE STUDY OF NIGER-DELTA AREA)

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TITLE PAGE

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THE CHEMICAL ENGINEERING DEPARTMENT

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BY

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IN PARTIAL FULFILLMENT OF THE REQUIREMENT FOR THE

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DECLARATION

I Kolo Ellah Mohammed of the department of Chemical Engineering in the school of Engineering and Engineering technology, Federal University of Technology Minna, Declared that this write-up is submitted as original work of my knowledge in partial fulfillment of the award of Bachelor of Engineering (B.Eng.). All information gotten from both published and unpublished work has been acknowledged in the write up.

SIGNATURE

23/11/2004
DATE

CERTIFICATION

This is to certify that the project title "EVALUATION OF GROUND-LEV CONCENTRATION OF POLLUTION DISPERSION DUE TO GAS FLARING" carried out Kolo Ellah Mohammed meets the requirement for the award of the degree, Bachelor Engineering (B.Eng.). In Chemical Engineering, Federal University of Technology, Minna, Ni State, Nigeria.

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DEDICATION

This research project is dedicated to the almighty Allah, who created the universe and taught mankind what he knew not, and also to the entire family of Alhaji Jubril Kolo Ahmed.

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My sincere gratitude to the almighty Allah, the All-Knowing and the guide for granting me the privilege to successfully carry-out this project.

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May Allah continue to workout his best plans in our lives.

ABSTRACT

The disposal of associated gases through flaring has been a major problem for the Nigerian Oil and gas industries and most of these gases are flared due to the lack of commercial out lets. Gas flaring activities resulting in changes of the atmosphere concentration and distribution of green house gas. The resultant effect of gas flaring are the damaging effect of the environment due to acid rain formation, green house effects, global warming and ozone depletion. This write-up is aimed at evaluating ground level concentration of CO_2, CO, SO_2, NO_2 and Total hydrocarbon (THC), which are product of gas flare in oil producing areas. Volumes of gas flare at different flow station were collected as well as geometrical parameters. The result of simulation of model developed based on the principles of gaseous dispersion by Gaussian showed a good agreement with dispersion pattern. The result showed that the dispersion pattern of pollutants at ground level depends on the volume of gas flared, wind speed, velocity of discharge and nearness to the source of flaring. The result shows that continuous gas flaring irrespective of the quality deposited in the immediate environment will in long run lead to change in the physio-chemical properties of soil.

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CHAPTER ONE

1.0 INTRODUCTION

The presence of unacceptable levels of foreign gaseous and particulate matter in the atmosphere is referred to as air pollution. This reduces the quality of air for human, plant and animals existence. Dangerous levels of contamination are detrimental to health and can lead to death. The natural gas which is an essential by-product of oil industry was first discovered in commercial quantity at olaboin, Bayelsa state in 1956 by shell petroleum Development Company of Nigeria Limited formerly shell "D" area (Iyaye, 1997). Similarly in 1962 EIF Petroleum Nigeria Limited formerly "Safrab" discovered oil in commercial quantity and gas as a by-product at Obagi in Egi land of River State. During this period, there was no significant market for Nigeria gas, as such no system for collection and preservation of the associated gas. Thus there was indiscrimination flaring of the gas(Ajayi, 1998). Gas flaring is a method used to dispose off the natural gases associated with the Crude oil. The flared gas consist of numerous other gases such as hydrogen sulphide, Sulphurdioxide, Nitrogendioxide, Carbondioxide, Water vapour, Hydrocarbon gases e.t.c. (Ajayi, 1998).

Pollutants are emitted into the atmosphere as either gases or particles and are eventually removed by natural self cleaning process. The waste mostly originates from the burning of fossil fuel and the processing of materials by industries. Other sources includes waste from burning engines in cars, fuel used in domestic sectors, oil boom, gas flaring agricultural processes but of all this, the process industries have been recognized as the major source of air pollution. The self-cleansing ability of the atmosphere which involves dispersion and dilution is used as a grant channel is presently too small and cannot match up to the rate of introduction of pollutants in to the atmosphere; this is due to meteorological influences. Experts have been able to identify air pollution by industries as a major problem (Shamaki: 2003).

The releases of the flared gas residue into the atmosphere have caused a lot of hazard characteristics of the petroleum industry. Some of the hazards associated with gas flaring include heavy noise, increase in temperature and emission of organic compound and particles that are dangerous to the ecosystem. The needs to ascertain the effect of flaring are quite overwhelming because of the fact that free radical and atoms that control the atmospheric chemistry but present in low concentration readily react with gaseous substance in the atmosphere to give distribution in the ecosystem. In recent times gas flaring has become one of the major typical issues of concern to communities in the Niger-Delta (Iyaye, 1997 and Ajayi, 1998). The contaminants released in to the atmosphere include carbon monoxide, carbondioxide, hydrocarbon, nitrogen oxide, particulate matter, sulphur oxide e.t.c. These contaminants are produced by burning of coal to run mills and machineries, drilling processes and purification of petrochemicals.

When gas flaring occur in oil producing area some is being absorbed on reaching the ground. The ground level concentrations of the gas flaring also have effect on the soil which actually affects the yielding of the plant. Most of the activities that occur in the soil are temperature dependent, the growth of bacteria, the growth of various species of plant depend on heat accumulation power of such a soil, organic matter decomposition, other microbial rate processes such as biodegradation of pesticides and other organic chemicals all depend on temperature of the soil. Therefore soil temperature is one of the most important factor that influence chemicals, physical and biological processes in soil and plant science. (Adeniyi, 2001).

The soil serves as a sink during the day and a source during the night because of its high heat storage capacity because of this property metabolically regulated plant processes such as water and nutrient update can be diminished below optimum rates at both low and high temperature, this brings about temperature dependent growth and yield patterns. The heat from gas flares coupled with solar radiation falls on the soil thereby heating it up. Areas that experience such a high temperature have lands that have been useless for cultivation. (Adeniyi, 2001).

This project focuses on some of the practical consideration of dispersion and also the extent of pollution in the atmosphere by these process industries, where mode of pollution is a continuous emission from point source which is a common industrial method of disposing waste gases. Air quality models describe the fate of air borne gases and particles, the most important consideration in dispersion of pollution is first known as the acceptable ground level concentration and as well as the varying ground level concentration. Topographic as well as meteorological condition must be put in to consideration.

1.1 AIMS AND OBJECTIVES

The aim and objectives of this project includes;

1. Evaluation of the ground level-concentration of pollutant dispersion of gas flaring by developing a predictive model for the dispersion of pollutants from flaring point.
2. To determine the height to which the plume rises at a given down wind distance from the plume sources and find interaction between the various parameters that affect pollution dispersion pattern i.e. volume of gas flared, temperature, wind speed, stack temperature, velocity of discharge e.t.c.
3. To simulate the developed predictive model using visual basic program.

1.2 SCOPE OF PROJECT

This project work focuses on the evaluation of ground level concentration of the gases i.e. CO_2, CO, NO_2, SO_2 and total hydrocarbon which occurs as a result of flaring of associated gases during the exploration of oil in the oil producing areas.

CHAPTER TWO

2.0 LITERATURE REVIEW

The term pollution has become a household word since its phenomena are on the increases and both animate and inanimate materials in the world at large feel its effect. Pollution can be said to be the action of releasing toxic material in to the environment .In other word pollution is the action of making land, water or air dangerously impure (dirty) or unfit for use ;while pollutants can best be describes as those substance that pollute or cause pollution (Ajayi; 1998). The physical environment is where all human beings, plants, animals live and it provide the resources and ecological process, which makes life possible. Healthy environment is essential to well being of the earth and its inhabitants, who depend on it for the air they breathe, the water they drink and the food they eat. There is thus a close relationship between man and his environment.If the environment is such away as to create hazard to health, safety or welfare of any living species. Pollution may occur naturally, but the term is more commonly applied to change brought by emission of industrial pollution by the careless discharged or disposal of human domestic waste or sewage (Agada, 2000). The term may also include the release of excess heat.

In 1995 the Niger-Delta environmental survey (NDES) stock holder seminar on optimization of the outcome of the survey observe with dismay that gas flaring emits pollution substance in to the atmosphere inducing heat in locality, scare living things and produces acid rain. The Niger-Delta environment survey (NDES) also observe that the awareness of people is growing every where about the direct relationship between their environment, culture and economy.

Gas flaring activities are changing the atmosphere concentration and distribution of green house gases and aerosols. These changes can produce a radioactive force by changing either the reflection or absorption of solar radiation, or the emission and absorption of terrestrial radiation (Houghton et al, 1996). The atmospheres is a self cleaning entity, but when the rate of generation of these contaminations from gas flaring exceeds the rate of removal accumulation occur thereby causing environmental hazard. Such major contaminants resulting from gas flaring are Carbon dioxide, carbon monoxide, Sulphur dioxide, Nitrous oxide and Chlorofluorocarbon (Akinfesaye, 1999). Gas flaring cause green house effect, thereby producing global warming and green house gases which include: water vapour, carbon dioxide, Methane, Nitrous oxide; Ozone, Carbon monoxide and Nitrogen oxide. Some of the effects of gas flaring are discussed below;

2.1 EFFECTS OF GAS FLARING

In oil producing areas of the world, including Nigeria, natural gas is found mixed with the sub-surface crude oil. It is the "associated gas" which must be produced with crude oil that has to be flared if no way exists to utilize it. The resultant effects of gas flaring are the damaging effect in the environment due to Acid rain Formation, Green house effect, Global worming and Ozone depletion.

2.1.1 ACID RAIN FORMATION

When gas flaring occurs in oil producing area, it gives rise to the formation of acidic oxides of nitrogen, sulphur and carbon. The phenomenon of acid rain due to the dissolution of these acid gases in the atmospheric water in the sky so that it becomes acidic thereby leading to formation of rain with PH below 5.0 (Adeniyi, 2001). Its effect is usually by its corrosion of rooftops, discoloration of paints on building, premature rusting of metallic object, damage to flora and fauna (Plant productive parts). Below is the reaction between acid gases and atmospheric water to produce acidic oxide.

$$CO_2\,(g) + H_2O\,(l) \longrightarrow H_2CO_3\,(aq)$$

$$SO_3\,(g) + H_2O\,(l) \longrightarrow H_2SO_4\,(aq)$$

$$NO_2\,(g) + H_2O\,(l) \longrightarrow HNO_2\,(aq) + HNO_3\,(aq)$$

2.1.2 GREEN HOUSE EFFECT

The earth naturally absorbs and reflects incoming solar-radiation and emits larger wave length terrestrial (thermal) radiation back in to space. On average, the absorbed solar radiation is balanced by the outgoing terrestrial radiation, through itself absorbed by gases in the atmosphere. The energy from this absorbed terrestrial radiation warms the earth surface and atmosphere, creating what is known as the "natural green house effect" without the natural heat trapping properties of these atmosphere gases, the average surface temperature of the earth would be about 33^0C lower (Houghton et al 2001)

2.1.2.1 GREEN HOUSE GASES

The green house effect is primarily a function of the concentration of he concentration of water vapour, Carbon dioxide and other trace gases in the atmosphere that absorb the terrestrial radiation leaving the surface of the earth (Houghton et al, 1996)(. The change in the atmospheric concentration of these green house gases can alter the balance of energy transfer between the atmosphere space, land and oceans. Natural occurring green house gases include carbon dioxide (CO_2), water vapour, methane (CH_4), Nitrous oxide (N_2O) and ozone (O_3). Several classes of halogenated substances that contain fluorine, chlorine or bromine are also part of green house gases which are produced in the industries, e.g. chlorofluorocarbon (CFC) and bromoflurocarbon (BFC). (Houghton et al, 2001). Some of the green house gases are discussed below.

2.1.2.1.1 CARBON MONOXIDE

Eighty percent (80%) of carbon monoxide (CO) emitted is from transportation i.e. the incomplete combustion of fuel. In fact carbon monoxide is produced almost entirely by artificial process including transportation, industrial process e.t.c. Since the primary source of carbon monoxide (CO) is the internal combustion engine, the maximum levels of the gas occur in congested urban areas during rush hours. At such times carbon monoxide levels in the air in the metropolis may rise up to 50-100 ppm whereas, in places very remote from urban centers, the carbon monoxide (CO) level may be low as 0.09 ppm (George, 2000).

2.1.2.1.2 CARBON DIOXIDE

It is always said that carbon dioxide is not a pollutant in the conventional sense, because it is a normal component of the atmospheric air (0.335) essential for plant growth (USA Embassy, 1995). But during flaring carbon dioxide is produce through the combustion of fossil fuel. When the hydrocarbon gases are limited, they decompose in to hydrogen and carbons, hydrogen combined with oxygen in air to produce water (steam), while the carbon yield. Carbon dioxide in the presence of oxygen.

$$C(s) + O_2(g) \longrightarrow CO_2(g)$$

2.1.2.1.3 NITROUS OXIDE (N_2O)

Anthropogenic sources of Nitrous oxide emission include agricultural soils, fossil fuel combustion, waste water treatment, waste combustion and biomass burning. Nitrous oxide is primarily removed from the atmosphere by the photolytic action of sunlight in the atmosphere (Shamaki, 2003).

2.1.2.1.4 NITROGEN OXIDE

The primary climate change effects of nitrogen oxides (i.e. NO and NO_2) are indirect and result from their role in promoting the formation of Ozone in the troposphere and to a lesser degree, lower stratosphere, where it has positive radioactive forcing effects. NOx are created from lighting, soil microbial activity, biomass burning (both natural and anthropogenic fires), fuel combustion and in the stratosphere, from the photo-degradation of nitrous oxide (N_2O).Concentration of NOx is both relatively short-lives in the atmosphere and spatially variable (Penner,1999).Side effects of nitrogen oxide include irritation to eyes, nose, and throat, increased susceptibility of animals and humans infection.

$$N_2O + O \longrightarrow 2NO$$

$$NO + O_3 \longrightarrow NO_2 + O_2$$

$$N_2O + O \longrightarrow NO + O_2$$

2.1.2.1 SULPHUR DIOXIDE

Sulphur dioxide partakes in complex reaction which produces SO_3 and SO_4. Sulphur dioxide is obtained majorly from burning of fossil fuels, especially in power plant, industries processes (e.g. flaring) that include refining of petroleum and other products. The sulphur dioxide reacts with oxygen and water to form H_2SO_4.

$SO_2 + O_2 + H_2O \longrightarrow H_2SO_4$

$H_2SO_4 + n\,H_2O \longrightarrow nH_2O\,.\,(H_2SO_4)$.

The aggregation of these polymolecules produces aerosols, which have destructive effect on both plant and animal (Shamaki, 2003).

2.1.2.1.6 OZONE (O_3)

The past increase in troposphere Ozone, which is also a green house gas, is estimated to provide the third largest increase in direct radiative forcing since the pre-industrial era, behind carbon dioxide and methane, troposphere Ozone is provided from complex chemical reaction of volatile organic compound mixing with nitrogen oxide (NO), (Houghton et al, 2001)

2.1.2.1.7 WATER VAPOUR (H_2O)

Overall, the most abundant and dominant green house gas in the atmosphere is water vapour, water vapour is neither long-lived nor well mixed in the atmosphere, varying spatially from)0 to 2%. A warmer atmosphere has an increased water holding capacity, yet increased concentration of water vapour affects the formulation of clouds, which can both absorb and reflect solar and terrestrial radiation (Houghton et al, 1996).

2.1.3 EFFECTS OF GAS FLARED ON THE SOIL

Organic chemical all depend on temperature of the soil. Most of the activities that occur in the soil are temperature dependent , the growth of bacteria, the growth of various species of plant independent on the heat accumulation power of such a soil, organic matter decomposition, other microbial rate processes such as biodegradation of pesticides. (Shamaki, 2003). Therefore soil temperature is one of the most important factors that influence chemicals, physical and biological process in soil and plant science. The soil serves as a sink during the day and a source during the night because of its high heat storage capacity, because of this property, metabolically regulated plant processes such as water and nutrient update can be diminished below optimum rates at both low and high temperature, this brings about temperature dependent growth and yield pattern;. The heat from gas flared coupled with solar radiation falls on the soil thereby heating it up. Areas that experience such a high temperature have lands that have been useless for cultivation (Adeniyi, 2001).

2.1.4 EFFECTS OF GASEOUS POLLUTION ON HEALTH

The effects of gaseous pollution on the respiratory system depend on the concentration, period of exposure and the solubility. High soluble gases such a sulphur oxide are absorbed in the upper part of the respiratory system where as relatively insoluble gases like CO, NO_2 and O_3 penetrate deep and reach the alveoli of the hugs. Some of adverse effects of these pollutants include pulmonary oedema emphysema and prevention of oxygen to the blood (Olabanji, 2003). Some of effects of these gases on health are discussed below;

2.1.4.1 SULPHUR DIOXIDE

Sulphur dioxide has its primary effect on the respiration tract, producing irritation and increasing airway resistance, it increase mucus secretion, also SO_2 has been implicated in several acute accidents of air pollution. During a S-day period marked by a temperature inversion on a fog in London in December 1952, about 3500-4000 death in excess of normal were recorded. Autopsies revealed irritation of respiratory tract and high level of SO_2 were suspected as being responsible (George, 2000). The primary threat of SO_2 to urban atmosphere may arise not from SO_2 itself but from the change it undergoes in the atmospheres such as the formation of H_2SO_4 and sulphate aerosols. The sulphate particle can be carried deep in to the hug causing even more severe health problems. SO_2 also can be absorbed in small particle such as the salts of won management and vanadium present of air. SO_2 is oxidized to H_2SO_4 and the particulate acts in enhancing the oxidation process (Olabanji, 2003)

2.1.4.2 CARBON MONOXIDE

Carbon monoxide, when inhaled passes through the lungs and diffuses into the blood stream, it combines with the red blood pigment called haemoglobin forming Carboxy-haemoglobin cloth. The affinity of carbon dioxide for haemoglobin is 210 times greater than that of oxygen for body tissue in 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 cloth in the blood retards the dissociation of remaining oxy-haemoglobin, so the tissues are further deprived of oxygen (Abdullahi, 2000).

2.1.4.3 OXIDES OF NITROGEN

Nitrogen oxides have much the same effect as Carbon monoxide, reducing the oxygen carrying capacity of the blood. Studies on animals have demonstrated a variety of other toxic effect of nitrogen oxide, principally involving the lungs. NO is bio-chemically relatively inert and not very toxic. Like CO and NO_2, it attaches itself to the haemoglobin of the blood and reduces the oxygen-carrying capacity of the haemoglobin. However in polluted air, the concentration of NO is normally too low to produce any noticeable effect on the haemoglobin. Acute exposure to nitrogen dioxide (NO_2) can be quite harmful and the effects vary with concentration and duration of exposure. For exposure ranging from several minutes to one hour, a level of 50 – 100 ppm NO_2 cause inflammation of lung tissue for periods of 6 – 8 weeks after which time the subject normally records. Exposure problem which is fatal within 3 – 5 weeks after exposure. Death generally results from 2 to10 days after exposure to 500 ppm or more of NO_2, NO_x (Oxide of Nitrogen) are known to cause fading of dyes in some textile (though not health hazard) (George, 2000)

2.1.4.4 HYDROCARBON AND PHOTOCHEMICAL OXIDANTS

At the concentration usually found in urban air, the hydrocarbons cause no adverse effect on human health. Aliphatic hydrocarbons produce undesirable effect only at concentration 10^2 to 10^3 times a higher than those usually found in the atmosphere. NO effects have been observed for level below 500 ppm. Aromatic hydrocarbons are more reactive than aliphatic ones and cause irritation of the mucus membrane. The major oxidation produced in petrochemical smog is ozone contrary to the popular belief; ozone appears to have no effect on the eyes at usual urban concentration. The respiratory systems however may respond to very low concentrations. Many other oxidations are produced in petrochemical Smog. Particularly are the peroxyacloitrate (PANS) causes eye irritating, oxidants such as PAN and peroxybenzolynitrate (PBN), irritates the nose and throat and cause chest constriction which aggravates asthma (Agada, 2000).

2.1.4.5 PARTICULATES

Particulates are the sum total air pollution to most people because these particles are large enough to be seen. They range from 1 – 10 microns in diameter over 130 million ton of soot, dust and smoke particulate are deposited into atmosphere by automobile and industries. Trash burning, forest fires and jet aircraft deposits another 30 million tons. Particulate many cause physical damage of certain material particles whipped by the wind grind exposed materials by abrasive action particles settling in electronic equipment can cause break down in resistance and foul contacts and switches particles may interfere (Abdullahi, 2000). Physically without or more of the clearance mechanism in the respiratory tract of man and animals(inhibiting ciliary transport of mucus) for example people who have asthma know that heavy concentrations particle in the air increases discomfort. In extremely polluted regions, these diseases often lead to death. Particulate may also injure human beings or animals because they are inherently essentially toxic. Lead compound are emitted in automobile exhaust. Particles containing fluorides commonly emitted from aluminum producing and fertilizer factories have weathering of bones and loss of mobility in animals which have eaten plants covered by the dust (George, 2000).

2.1.5 EFFECTS OF AIR POLLUTION ON VEGETATION

Vegetation is more sensitive than animals to many 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 silvering of leafy vegetation by oxidants, the consumer however usually will not buy such vegetables on aesthetic ground, so the grower still sustains a loss. (Olabanji, 2000).

2.1.6 GLOBAL WARMING

Some gases in the atmosphere permit the sun radiation to heat the earth but do not permit the infrared radiated back out by the earth to escape in to space. These gases such as carbon dioxide, methane, nitrous oxide and water vapour are responsible for maintaining a global temperature acceptable to living. This is referred to as the green house effect However; within the last century the amount of carbon dioxide in the atmosphere has increased due to fossil fuel consumption, petroleum and it deviate. This has given rise to increase in global temperature by about 1°C, atmosphere scientists have attributed this to human activities and they have predicted that unless drastic action is taken, temperature will continue to rise by between 1°C and 3.5°C over the next century (Shamaki, 2003). This increase in temperature can cause great consequence such as rise in see level, extinction of some plant and animal increase in the frequency of severe hurricanes and droughts. There is also a risk of the emergence of disease also degradation of natural ecosystem, could lead to reduced biological activities (Adeniyi, 2001).

2.2 METEOROLOGICAL GAS FLARED DISPERSION

Dispersion of pollution (e.g. flaring) is dependent on atmospheric conditions, wind transport and diffuse contaminant, rain may wash them to the earth surface under cloudless skies, and solar radiation may induce important photochemical reactions. Wind velocity and direction determine the rate and direction or area in to which the pollution is carried, dilution of contaminants, from a source is directly proportional (other factors being constant) to wind speed, which also determine the intensity of mechanical turbulence produced as the wind blows over and around surface objects such as trees and building (Mc Graw Hill, encyclopedia of science and technology Vol. 1, 1999) Eddy diffusion by wind turbulence is the primary mixing agent in addition to mechanical turbulence generally dispersion frequently follows a daily cycle. In late evening with clear sky, the earth radiate heat to space cooling more rapidly than the air above this creates as inversion that last throughout the night, wind direction and pollution accumulation at the base of inversion layer.

2.3 MODELING AND SIMULATION

MODELING

Modeling could be defined as the process of translating a problem from its real environment to a mathematical environment in which it is more conveniently studied. Mathematical models are created using mathematical concepts such as functions and equations.

Mathematical models must be sufficiently simple, easy grasping and with clear idea about all the qualitative aspects of the phenomenon of interest many different model can be developed for lacking the same problem. Some model may be better than other in the sense that they are more useful or more accurate, but this is not always so.

Generally the success of a model depends on how easily it can be used and how accurate is it predictions. Note also that any model will have a limited range of validity not be applied outside this range.

SIMULATION

The implementation and validation of model is the simulation. Simulations represent the application of modeling techniques to real systems, this enable 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 optimize operation quickly and safely and it can be used to provide in depth knowledge about complete system behavior to improve and facilitate cost calculation and planning of operation.

Simulation method 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.

2.3.1 MODELING METHODOLOGY

It is fairly widely recognized that there are a number of major steps in building and using mathematical model. These are stated as follows;

a) Recognition that a problem exist
b) Familiarization with the system to be modeled
c) Formulation of the problem
d) Construction of the model
e) Validation of the model
f) Analysis of the model
g) Interpretation of result
h) Implementation
i) Monitoring of the system and model.

CHAPTER THREE

3.0 EXPERIMENTAL ANALYSIS

The experimental analysis methods carried out in this project is aimed at quantifying the volume of gas flared at flow station in the Niger-Delta area for different stations. THE experiments were performed by industrial process situated in the Niger-Delta area. The Data were collected from their log book.

CHAPTER FOUR

4.0 MATHEMATICAL MODELING TO DETERMINE GROUND LEVEL CONCENTRATION OF POLLUTANTS FROM GAS FLARED

The mathematical model of a system is the mathematical description of that system. It translates the phenomenon occurring in the physical/chemical process in to quantitative mathematical equation. A model thus is aimed at providing the simplest possible description of a system without losing the essential feature and behavior of the system. The system of interest here is the ground level concentration of pollutants from gas flared.

A pollutant concentration may be considered either as a climatologically parameter in the same way as air temperature or humidity or as a complex resultant of "Pure" climatologically parameter (wind rise, Stability wind rise temperature e.t.c.). Every population of climatological decryptions is essentially random. Since every function of a random variable is also a random variable, the concentration will be subjected to random variation similar to that of climatological series. The modeling is a resultant of purely climatologically. To compute base on climatological parameter, an adequate amount of meteorological input about the state of the atmosphere as well a detailed data about emission were collected.

During the development of the mathematical model for the ground level concentration of pollutant using the g round level concentration of pollutant using the Gaussian formula, the following assumption were made

1. Vertical and cross wind diffusion occur according to Gaussian distribution.
2. Downwind diffusion is negligible compared to down wind transport
3. The emission rate, Q is continuous and constant.
4. There is no deposition, washout, chemical conversion or absorption of emissions and any emission diffusing to the ground are reflected back in the plume (i.e. all emissions are totally conserved within the plume).
5. Incomplete combustion.

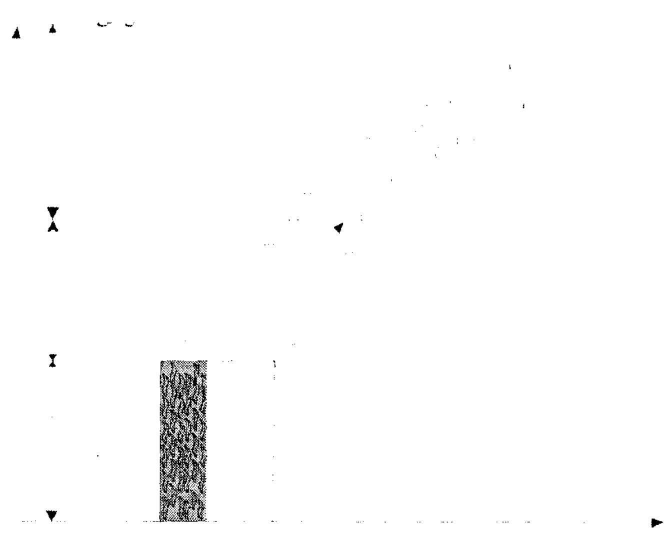

Fig 1. Schematic diagram of Gas flared.

The Gaussian distribution equation is written below

$$\frac{n_i}{\wedge} = \left(\frac{n_m}{\wedge}\right) e^{-(xi-xm)^2/2\delta^2} \quad \text{...(1)} \quad \text{(Beychok, 1995)}$$

Where δ = standard deviation, which is a measurement of distribution of the class characteristics among its sub-classes.

X_m = the mean or arithmetic average value of the class characteristics amongst the total population.

$X_i - X_m$ = deviation in amount of class characteristics between member of sub-class I and mean sub-class n.

n_i = population of a specific sub-class

n_m = the mean population of sub-class

$\wedge$ = interval of the measurement characteristic.

Take interval of the measurement characteristic to be 1 unit. Then equation (1) reduces to;

$$n_i = n_m e^{-(Xi - Xm)2/2\delta^2} \quad \text{..(2)}$$

Given the δ and X_m of a class distribution, equation (2) will provide the ration of any sub class population to the mean sub class population to the mean sub class population (n_i/n_m). Since we are dealing with stack gas dispersion, it is more useful to relate this population. For simplification we set ($X_i - X_m$) to be equal to U and the equation (2) is integrated to obtain the area under the curve which is the total class population N. Since that area is the summation of the rectangle having the height n_i and Δu.

$$N = \sum_{\infty}^{\infty} (n_i Du) = \int_{\theta}^{\theta} n_i du \quad \ldots\ldots(3)$$

But $n_i = n_m e^{-(U)^2/2\delta^2}$

Then equation (3) becomes;

$$N = \int_{\infty}^{\infty} n_m e^{-(u)^2)/2\delta^2} du \quad \ldots\ldots(4)$$

$$N = n_m \int_{-\infty}^{\infty} n_m e^{-(u)^2)/2\delta^2} du \quad \ldots\ldots(5)$$

$$N = n_m \int_{-\infty}^{\infty} n_m e^{-\frac{1}{2}(u/\delta)^2} du \quad \ldots\ldots(6)$$

$$N = nm \int_{-\infty}^{\infty} n_m e^{-\left[(\delta\sqrt{2})^{-1} U\right]^2} du \quad \ldots\ldots(7)$$

But $\int_{-\infty}^{\infty} e^{-U^2} du = \sqrt{\Pi}$

For total area under the curve of function that is symmetry about axis (i.e. $n = e^{-u^2}$).

Therefore, the area under the curve will be $= (2\pi)^{1/2}$

From equation (7) the integration yield

$$N = n_m \delta (2\pi)^{1/2} \quad \ldots\ldots(8)$$

Dividing equation (2) by equation (8)

$$\frac{ni}{N} = \frac{n_m e^{(xi-xm)^2} / 2\delta^2}{n_m \delta (2\Pi)^{1/2}}$$

$$\frac{ni}{N} = \frac{e^{(xi-xm)^2} / 2\delta^2}{\delta (2\Pi)^{1/2}} \quad \ldots\ldots(9)$$

Finally Equation (9) can be re-arranged in the form that has been widely utilized to develop stack gas dispersion models based upon the Gaussian distribution

$$ni = \frac{Ne^{-(xi-xm)^2} / 2\delta^2}{\delta(2\Pi)^{1/2}} \qquad \text{...(10)}$$

The dispersion of emission from a continuous point source may be visualized as the conical plume. As the plume travels downwind, it may be further visualized as a series of disc-shapes increment which are diffusing and expanding in the vertical and crosswind dimension, thus at any downward distance x, the total volume (from the source to the point x) retains all of the emission released during the time required for the wind to travel from the source to point x.

Q ($^x/_u$) = weight of emission in total plume from source to point x.

Where Q = point-source emission g/sec

U = horizontal wind velocity, m/sec

X = distance from point source, m

Considering the total emission of the vertical dimension from a far distance and hence integrate crosswind emission in the 1 meter thick increment, without regard to any diffusion in the y-dimension using the Gaussian distribution equation (10) the expression becomes;

$$n^r(x_i Z) = \frac{Ne^{(Zri-Zm)} / 2\delta^2}{\delta(2\Pi)^{1/2}} \qquad \text{...(11)}$$

N = total gram of emission

Z_r = any receptor location in the Z-dimension where the emission density is determine.

Z_m = location of the mean emission density (i.e. the plume center line) in the Z-dimension

δ_z = vertical standard deviation of the emission densities.

Assuming that any emission reaching the ground (which is a barrier) is totally reflected upward since we have already assumed no deposition, washout or absorption. To determine n_r at any ground level or above ground in the Z-dimension including upward reflection from the ground. In the 2-dimension, the Gaussian equation becomes;

$$n^r(x_1 Z) = \frac{Ne^{(Zri - Zm)} / 2\delta^2{}_Z}{\delta_Z (2\Pi)^{1/2}} + \frac{Ne^{(Zri - Zm)} / 2\delta^2{}_Z}{\delta_Z (2\Pi)^{1/2}} \quad (12)$$

Substitute the following into equation (12)

$N = {}^{Q}/_{U}$, $Z_r - Z_m = H_r - H_e$, $Z_r' - Z_m' = (H_r - (-H_e) = H_r + H_e$

Where;

H_e = height of plume centerline above the ground, M

H_r = height of receptor above ground m,

Therefore equation (12) becomes;

$$n_r(x,z) = \frac{Qe^{-(Hri - He)^2} / 2\delta^2{}_Z}{u\delta_Z (2\Pi)^{1/2}} + \frac{Qe^{-(H'r + H'e)^2} / 2\delta^2{}_Z}{u\delta_Z (2\Pi)^{1/2}}$$

$$= \frac{Q}{U\delta_Z (2\Pi)^{1/2}} \left(e^{-(Hri - He)^2} / 2\delta^2{}_Z + e^{-(H'ir + H^2e)^2} / 2\delta^2{}_Z \right) \quad \text{.....................(13)}$$

Taking the crosswind Gaussian distribution of $n_r(x,z)$ in the y-dimension in to consideration.

$$n_r(x,y,z) = \frac{n_r(x_r Z) \; x \; e^{-(Y - Y_m)^2 / 2\delta^2{}_Y}}{\delta_Y (2\Pi)^{1/2}} \quad \text{..(14)}$$

$$\text{But } n_r(x, z) = \frac{Q}{U\delta_Z (2\Pi)^{1/2}} \left(e^{-(Hri - He)^2} / 2\delta^2{}_Z + e^{-(H'ir + H^2e)^2} / 2\delta^2{}_Z \right)$$

Equation (14) becomes

$$n_r(x,y,z) = \frac{\frac{Q}{U\delta_Z (2\Pi)^{1/2}} \left(e^{-(Hri - He)^2} / 2\delta^2{}_Z + e^{-(H'ir + H^2e)^2} / 2\delta^2{}_Z \right) x \; e^{-(Y - Y_m)^2 / 2\delta^2{}_Y}}{\delta_Y (2\Pi)^{1/2}} \quad \text{......... (15)}$$

$$n_r(x,y,z) = \frac{Q}{U\delta d_Z 2\Pi} \left(e^{-(Hri - He)^2} / 2\delta^2{}_Z + e^{(H'ir + H^2e)^2} / 2\delta^2{}_Z \right) x \; e^{-(Y - Y_m)^2 / 2\delta^2{}_Y} \quad \text{................ (16)}$$

There is no diffusion barrier in the crosswind dimension and hence no need for another reflection term in equation (16)

Also make this substitution into equation (16)

$C = n_r(x,y,z)$ to confirm with convention

$Z_r = H_r$ to conform with conversion

$Y_m = 0$, for the location of the mean emission density at the plume centerline in the crosswind or y-dimension

Y = Distance from the receptor to the plume centerline in the crosswind or y-dimension

$$C = \frac{Q}{U\delta d_z 2\Pi} e^{-y^2/2\delta y^2}\left(e^{-(Zr-H_e)^2} / 2\delta^2{}_z + e^{-(Zr^1+He^1)^2/2\delta^2{}_z} \right) \ldots\ldots\ldots\ldots\ldots\ldots(17)$$

Where;

C = Concentration of emission, g/m^3 at any receptor located at x meter downwind,

y-meter acrosswind from the centerline

z-meter above ground

Q = source emission rate g/sec

U = horizontal wind velocity m/sec

δ_z = vertical standard deviation of the emission distribution, M

δ_y = horizontal standard deviation of the emission distribution, M.

The receptor is at Z_r, which is equal to zero at that point for that case of equation (17) reduces to;

$$C = \frac{Q}{2\Pi U\delta y\delta_Z} e^{-y^2/2\delta y^2}\left(e^{-(H_e)^2} / 2\delta^2{}_Z \right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(18a)$$

or the equivalent form of

$$C = \frac{Q}{2\Pi U\delta y\delta_Z} e^{-\left(y^2/2\delta y^2 \right) - \left((H_e)^2 / _2\, \delta^2{}_Z \right)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(18b)$$

The composition of gas flared in their percentage is given below

CH_4	47%
C_2H_6	18%
C_3H_8	20%

C_4H_{10}	5%
C_5H_{12}	9 %
H_2S	0 03%
NO_2	0 022%

The following equations below are the incomplete combustion of flared gases

$2\ CH_4 + 7/2\ O_2 \longrightarrow CO_2 + CO + 4\ H_2O$

$C_2H_6 + 3\ O_2 \longrightarrow CO_2 + CO + 3\ H_2O$

$C_3H_8 + 4\ O_2 \longrightarrow CO_2 + 2\ CO + 4\ H_2O$

$C_4H_{10} + 5\ O_2 \longrightarrow CO_2 + 3\ CO + 5\ H_2O$

$C_5H_{12} + 13/2\ O_2 \longrightarrow 2\ CO_2 + 3\ CO + 6\ H_2O$

$H_2S + O_2 \longrightarrow SO_2 + H_2$

$N_2 + 2O_2 \longrightarrow 2\ NO_2$

To calculate the volume of each pollutant produced by the flared gas.

Basis $1 m^3$ of gas being flared

For carbon dioxide (CO_2)

From the above table $CH_4 = 47\%$

$47 / 100 \times 1 = 0.47 m^3$

Let the stack efficiency be equal to E_s

$E_s / 100 \times 0.47 = 0.0047\ E_s\ (m^3)$

From the equation above the mole of CH_4 to that of CO_2 is 2:1

Therefore 2 moles of CH_4 gives 1 mole of CO_2

$0.0047\ E_s\ (m^3)$ of CH_4 gives 2 moles of CH_4

$x\ (m^3)$ of CO_2 gives 1 mole of CO_2

$\therefore \frac{0.0047\ E_s\ (m^3) \times 1}{2} = 0.0023e\ E_s$

$\therefore$ CO_2 from CH_4 = 0.00235 E_s

CO_2 from ethane (C_2H_6) will be

C_2H_6 = 18%

The mole reaction of C_2H_6 to CO_2 is 1:1

$18 / 100 \times 1m^3 = 0.18\ m^3$

$E_s / 100 \times 0.18\ m^3 = 0.0018\ E_s\ (m^3)$ of C_2H_6

Since the mole ratio is 1:1

CO_2 from C_2H_6 will be 0.0018 Es (m^3)

For C_3H_8 we have

C_3H_8 = 20%

Mole ratio of C_3H_8 to CO_2 is 1:1

$20 / 100 \times 1\ m^3 = 0.2\ m^3$

$E_s / 100 \times 0.2\ m^3 = 0.002$ Es (m^3) of C_3H_8

Since mole ratio is 1:1

Thereby CO_2 from C_3H_8 will be 0.002 E_s (m^3)

For C_4H_{10},

C_4H_{10} = 5%

Mole ratio of C_4H_{10} to CO_2 is 1:1

$5 / 100 \times 1\ m^3 = 0.05\ m^3$

$E_s / 100 \times 0.05\ m^3 = 0.0005\ E_s\ (m^3)$ of C_4H_{10}

Since mole ratio is 1:1

Then for the CO_2

1 Mole of C_4H_{10} gives 5×10^{-4} of C_4H_{10}

1 Mole of CO_2 will give $5 \times 10^{-4} / 1 = 5 \times 10^{-4} E_s(m^3)$

$\therefore$ CO_2 from C_4H_{10} = 5 10^{-4} E_s (m^3)

For C_5H_{12},

$C_5H_{12} = 9\%$

Mole ratio of C_5H_{12} to CO_2 is 1:2

$9 / 100 \times 1 \text{ m}^3 = 0.09 \text{ m}^3$

$Es / 100 \times 0.09 \text{ m}^3 = 0.0009 E_s (\text{m}^3)$ of C_5H_{12}

Then for the CO_2

1 Mole of C_5H_{12} gives 2 moles of CO_2

1 Mole of C_5H_{12} gives $5 \times 10^{-4} (\text{m}^3)$

1 Mole of C_5H_{12} will give $9 \times 10^{-4} = 9 \times 10^{-4} E_s (\text{m}^3)$

$\therefore$ 2 moles of will give $9 \times 10^{-4} / 1 \times 2$

$= 0.0018 E_s (\text{m}^3)$ of CO_2

Therefore the total amount of CO_2 from 1 m^3 of CO_2 gas is given by the summation of the result of equation above

$CO_2 = (0.00235 E_s + 0.0018 E_s + 0.002 E_s + 0.0005 E_s + 0.0018)$

$= 0.00755 E_s$

For the Total Hydrocarbon (THC)

The incombustible part of hydrocarbon

i.e. (CH_4, C_2H_6, C_3H_8, C_4H_{10}) from flare gas is the total hydrocarbon as calculated below.

For CH_4 $(0.47 - 0.00235 E_s) \text{ m}^3$

For C_2H_6 $(0.18 - 0.0018 E_s) \text{ m}^3$

For C_3H_8 $(0.2 - 0.002 E) \text{ m}^3$

For C_4H_{10} $(0.05 - 0.0005 E_s) \text{ m}^3$

For C_5H_{12} $(0.09 - 0.0018 E_s) \text{ m}^3$

$THC = (0.47 - 0.00235\ E_s)\ m^3 + (0.18 - 0.0018\ E_s)\ m^3 + (0.2 - 0.002\ E_s)\ m^3$

$+ (0.05 - 0.005\ E_s)\ m^3 + (0.09 - 0.0018\ E_s)\ m^3$

$THC = (0.99 - 0.00845\ E_s)\ m^3$

This is the amount of THC produced from of flared 1 m^3 gas.

For Sulphur dioxide (SO_2)

$H_2S + O_2 \longrightarrow SO_2 + H_2$

$H_2S = 0.03\%$

$0.03 / 100 \times 1\ m^3 = 0.003\ m^3$

$0.03 / 100 \times 0.0003 = 0.000003\ E_s\ (m^3)$ of H_2S

Form the equation above the mole ration of H_2S to SO_2 is 1:1. Therefore SO_2 from H_2S is $0.000003\ E_s\ (m^3) = 3.0 \times 10^{-6}\ E_s\ (m^3)$

For Nitrogen dioxide (NO_2)

$NO_2 = 0.022\%$

$NO_2 + 2O_2 \longrightarrow 2NO_2$

Mole ratio of N_2 to NO_2 is 1:2

$0.022 / 100 \times 1\ m^3 = 0.00022\ m^3$

$E_s / 100 \times 0.00022 = 0.0000022\ E_s\ (m^3)$

Form the equation above 2 moles of NO_2 produced from 1 Mole of N_2

$$\text{Therefore } \frac{2m3 \text{ of } NO_2 \times 2.2 \times 10^{-6} \text{ of } N_2}{1\ m^3 \text{ of } N_2}$$

$NO_2 = 4.4 \times 10^{-6}\ E_s\ (m^3)$

For carbon monoxide from the equation of incomplete combustion stated above;

The mole ratio of CH_4 to CO is 2:1

$47 / 100 \times 1\ m^3 = 0.47\ m^3$

$E_s / 100 \times 0.47\ m^3 = 0.0047\ m^3$

From the equation above the mole ratio of CH_4 to CO is 2:1

Thereby 2 moles of CH_4 gives $0.0047\ m^3$

1 mole of Co will give $0.0047 / 2 \times 1 = 0.00022\ E_s$

CO from $CH_4 = 0.0025\ E_s$

For C_2H_6, Mole ratio of C_2H_6 to CO is 1:1

$18 / 100 \times 1\ m^3 = 0.18\ m^3$

$E_s / 100 \times 0.18 = 0.0018\ E_s\ m^3$ of C_2H_6

Since the mole ratio are the same

Co from C_2H_6 is $0.0018\ E_s\ m^3$

For C_3H_8, Mole ratio of C_3H_8 to CO is 1:2

$20 / 100 \times 1\ m^3 = 0.2\ m^3$

$E_s / 100 \times 0.2 = 0.002\ E_s\ (m^3)$

1 mole of C_3H_8 gives $0.002\ E_s\ (m^3)$

$$2 \text{ Mole of CO gives } \frac{0.002\ Es\ (m^3) \times 2 \text{ mole of CO}}{1 \text{ Mole of } C_3H_8}$$

$$= 0.004\ E_s\ (m^3)$$

CO from C_3H_8 is $0.004\ E_s\ (m^3)$

For C_4H_{10}, the mole ratio of C_4H_{10} to CO is 1:3

$5 / 100 \times 1\ m^3 = 0.05\ m^3$

$E_s / 100 \times 0.05 = 0.0005\ E_s\ (m^3)$

1 mole of C_4H_{10} gives 0.0005 E_s (m^3) of C_4H_{10}

$\therefore$ 3 Mole of CO will gives $\frac{0.0005\ Es\ (m^3)\ of\ C_4H_{10} \times 3\ mole\ of\ CO}{1\ Mole\ of\ C_4H_{10}}$

= 0.0015 E_s (m^3) of CO

CO from C_4H_{10} is 0.0015 E_s (m^3)

For C_5H_{12}, the mole ratio of C_5H_{12} to CO is 1:3

9 / 100 × 1 m^3 = 0.09 m^3

E_s / 100 × 0.09 = 0.0009 E_s (m^3) of C_5H_{12}

1 mole of C_5H_{12} gives 0.0009 E_s (m^3) of C_5H_{12}

$\therefore$ 3 Mole of CO will gives $\frac{0.0009\ E_s\ (m^3)\ of\ C_4H_{10} \times 3\ mole\ of\ CO}{1\ Mole\ of\ C_5H_{12}}$

= 0.0027 E_s (m^3) of CO

CO from C_5H_{12} is 0.0027 E_s (m^3)

Therefore the total amount of CO from 1 m^3 of flare gas is given by the summation of the result of the equation above CO = (0.00235 E_s + 0.0018 E_s + 0.0015 E_s + 0.0027 E_s)

CO = 0.01235 E_s

Therefore the final equation for calculating the concentration of CO_2, CO, NO_2 and THC are

$$C_{co2} = \frac{7.55 \times 10^{-3}\ Es\ \rho v}{2\pi U \delta_y \delta_z}\ e^{-(y2 / 2\delta z2\ -(He)2 / 2\delta z2)}$$

$$C_{co} = \frac{0.01234\ E_s\ \rho v}{2\pi U \delta_y \delta_z}\ e^{-(y2 / 2\delta z2\ -(He)2 / 2\delta z2)}$$

$$C_{No2} = \frac{4.4 \times 10^{-6}\ Es\ \rho v}{2\pi U \delta_y \delta_z}\ e^{-(y2 / 2\delta z2\ -(He)2 / 2\delta z2)}$$

$$C_{THC} = \frac{(0.99 - 0.00845\ E_s)\ \rho v}{2\pi U \delta_y \delta_z}\ e^{-(y2 / 2\delta z2\ -(He)2 / 2\delta z2)}$$

$$C_{So2} = \frac{3.06 \times 10^{-6}\ E_s\ \rho v}{2\pi U \delta_y \delta_z}\ e^{-(y2 / 2\delta z2\ -(He)2 / 2\delta z2)}$$

Expression for δ, which is the rural dispersion coefficient of the emission distribution is given to be

$$\delta = \exp [I + J (\sin x) + K (\sin x)^2] \quad \ldots\ldots\ldots\ldots (19)$$

Where

δ = standard deviation of the emission distribution

x = downward distance in Km

$\exp [a] = e^a = 2.71828^a$

$a = [I + J (\sin x) + K (\sin x)^2]$

The constant I, J and K provided by Mc Muller for use in equation (19) are;

Pasquill Stability class	**For Obtaining δ_z**			**For Obtaining δ_y**		
	I	**J**	**K**	**I**	**J**	K
A	6.035	2.1097	0.2770	5.357	0.8828	-0.0076
B	4.694	1.0629	0.0136	5.058	0.9024	-0.0096
C	4.110	0.9201	-0.0020	4.651	0.9181	-0.0076
D	3.414	0.7371	-0.0316	4.2[illegible]0	0.9222	-0.0087
E	3.057	0.6794	-0.0450	3.922	0.9222	-0.0064
F	2 600	0.6564	-0.0540	3.533	0.9191	-0.0070

Where pasquill stability classes are

A = the very unstable class

B = unstable class

C = slightly unstable class

D = the neutral class

E = slightly stable class

F = the most stable class

In this project pasquill Stability Class A, D and F is choosing i.e. Unstable, neutral and stable atmosphere condition.

Also $H_e = h_s + hfv + \Delta h$ ......(20)

Where

H_e = Plume centerline height above ground

h_s = Stack height

hfv = Vertical flame height

But $hfv = 0.0042\ Qi^{0.478}$ ......(21)

Q_i = Stack gas sensible heat emission

$Q_e = C_{Ps}\ \rho_s\ V_s\ (T_s - T_a)$ ......(22)

ρ_s = Stack gas density

$$= \frac{\rho_a T_a}{T_s} \quad \text{(Beychock 1995)} \quad \text{......(23)}$$

$hfv = 0.0042\ (C_{\rho s}\ (\rho a\ Ta / Ts)\ Vs\ (Ts - Ta)\ 0.478$ ......(24)

Where;

$C_{\rho s}$ = Specific heat of stack gas, $Jkg^{-1}K^{-1}$

ρ_a = Ambient air density Kg / m^3

T_a = Ambient air temperature o / ∧

T_s = Stack gas temperature o / ∧

V_s = Stack gas flow, m^3/sec

And Δh = plume rise, m

$= 1.6\ F^{1/3} \times 2/3\ U^{-1}$ ......(25)

F = Brigg's buoyancy flux parameter m^4 / sec^3

$= (7.56 \times 10^{-7})\ (Qc)$ ......(26)

y = downward distance from stack, m

But x = 10 hs

U = wind velocity

$\therefore \Delta h = 1.6 (7\ 56 \times 10^{-7} Qc)^{1/3} (10\ hs)^{2/3} U^{-1}$ ....(27)

TABLE 4.1 – 4.2 BELOW ARE THE INPUT DATA USED FOR THE SIMULATION OF MODELING EQUATION USING VISUAL BASIC PROGRAM

JANUARY 2002

Input Data	U	Ts	Ta	ρa	Vs	hs	$C\rho_s$	Density Of The Pollutants				
								CO_2	CO	SO_2	NO_2	THC
Station 1	2.80	900	303	1.293	1.004	1.2	2200	1.977	1.25	3.125	1.874	0.718
Station 2	2.20	1000	304.5	1.293	2.998	1.2	2200	1.977	1.25	3.125	1.874	0.718

Table 4.1

FEBRUARY 2002

Input Data	U	Ts	Ta	ρa	Vs	hs	$C\rho_s$	Density Of The Pollutants				
								CO_2	CO	SO_2	NO_2	THC
Station 1	2.20	1000	309.5	1.293	0.898	1.2	2200	1.977	1.25	3.125	1.874	0.718
Station 2	2.75	1100	305.5	1.293	3.038	1.2	2200	1.977	1.25	3.125	1.874	0.718

Table 4.2

MARCH 2002

Input Data	U	Ts	Ta	ρa	Vs	hs	$C\rho_s$	Density Of The Pollutants				
								CO_2	CO	SO_2	NO_2	THC
Station 1	2.80	800	309.2	1.293	0.735	1.2	2200	1.977	1.25	3.125	1.874	0.718
Station 2	1.35	900	309.5	1.293	3.310	1.2	2200	1.977	1.25	3.125	1.874	0.718

Table 4.

APRIL 2002

Input Data	U	Ts	Ta	ρa	Vs	hs	$C\rho_s$	Density Of The Pollutants				
								CO_2	CO	SO_2	NO_2	THC
Station 1	1.39	750	308	1.293	0.706	1.2	2200	1.977	1.25	3.125	1.874	0.718
Station 2	1.28	1100	306.5	1.293	7.024	1.2	2200	1.977	1.25	3.125	1.874	0.718

Table 4.4

MAY 2002

Input Data	U	Ts	Ta	ρa	Vs	hs	Cρ$_s$	Density Of The Pollutants				
								CO_2	CO	SO_2	NO_2	THC
Station 1	2.20	1110	306	1.293	0.909	1.2	2200	1.977	1.25	3.125	1.874	0.718
Station 2	1.75	1000	310	1.293	5.167	1.2	2200	1.977	1.25	3.125	1.874	0.718

Table 4.5

JUNE 2002

Input Data	U	Ts	Ta	ρa	Vs	hs	Cρ$_s$	Density Of The Pollutants				
								CO_2	CO	SO_2	NO_2	THC
Station 1	1.81	880	303	1.293	0.860	1.2	2200	1.977	1.25	3.125	1.874	0.718
Station 2	2.0	950	306.6	1.293	4.500	1.2	2200	1.977	1.25	3.125	1.874	0.718

Table 4.6

JULY 2002

Input Data	U	Ts	Ta	ρa	Vs	hs	Cρ$_s$	Density Of The Pollutants				
								CO_2	CO	SO_2	NO_2	THC
Station 1	1.80	980	307.6	1.293	0.939	1.2	2200	1.977	1.25	3.125	1.874	0.718
Station 2	1.94	900	304	1.293	4.192	1.2	2200	1.977	1.25	3.125	1.874	0.718

Table 4.7

AUGUST 2002

Input Data	U	Ts	Ta	ρa	Vs	hs	Cρ$_s$	Density Of The Pollutants				
								CO_2	CO	SO_2	NO_2	THC
Station 1	1.39	900	306.5	1.293	0.876	1.2	2200	1.977	1.25	3.125	1.874	0.718
Station 2	1.38	1050	303	1.293	5.116	1.2	2200	1.977	1.25	3.125	1.874	0.718

Table 4.8

SEPTEMBER 2002

Input Data	U	Ts	Ta	ρa	Vs	hs	Cρ$_s$	Density Of The Pollutants				
								CO_2	CO	SO_2	NO_2	THC
Station 1	2.78	1100	306.3	1.293	0.561	1.2	2200	1.977	1.25	3.125	1.874	0.718
Station 2	2.0	1100	305.1	1.293	5.424	1.2	2200	1.977	1.25	3.125	1.874	0.718

Table 4.9

OCTOBER 2002

Input Data	U	Ts	Ta	ρa	Vs	hs	$C\rho_s$	Density Of The Pollutants				
								CO_2	CO	SO_2	NO_2	THC
Station 1	2.78	1000	307	1.293	0.719	1.2	2200	1.977	1.25	3.125	1.874	0.718
Station 2	1.38	850	306	1.293	4.620	1.2	2200	1.977	1.25	3.125	1.874	0.718

Table 4.10

NOVEMBER 2002

Input Data	U	Ts	Ta	ρa	Vs	hs	$C\rho_s$	Density Of The Pollutants				
								CO_2	CO	SO_2	NO_2	THC
Station 1	1.38	780	305	1.293	1.067	1.2	2200	1.977	1.25	3.125	1.874	0.718
Station 2	1.39	900	309	1.293	4.781	1.2	2200	1.977	1.25	3.125	1.874	0.718

Table 4.11

DECEMBER 2002

Input Data	U	Ts	Ta	ρa	Vs	hs	$C\rho_s$	Density Of The Pollutants				
								CO_2	CO	SO_2	NO_2	THC
Station 1	1.28	1000	308	1.293	1.080	1.2	2200	1.977	1.25	3.125	1.874	0.718
Station 2	2.6	950	307.1	1.293	4.980	1.2	2200	1.977	1.25	3.125	1.874	0.718

Table 4.12

CHAPTER FIVE

5.0 RESULTS AND DISCUSSION OF THE RESULT

5.1.0 RESULTS

5.1.1 EXPERIMENTAL RESULT

Experimental results are presented in Table 5.1.1 and 5.1.2 below

Table 5.1.1 shows volume of gas flared (m^3/s) at various times for station 1

Month	Volume of gas flared (m^3/s)	Discharge Velocity (m/s)	Wind Speed(m^3/s)	Stack Temp.(^0c)
Jan	1.004	18.0	2.80	900
Feb.	0.898	17.5	2.20	1000
March	0.735	17.5	2.80	800
April	0.706	13.0	1.39	750
May	0.909	14.0	2.20	1100
June	0.860	17.5	1.81	880
July	0.989	14.0	1.80	980
Aug.	0.876	12.0	1.39	900
Sept.	0.561	12.0	2.78	1100
Oct.	0.719	13.0	2.78	1000
Nov.	1.067	17.5	1.38	780
Dec.	1.080	13.5	1.28	1000

Table 5.1.2 shows volume of gas flared (m^3/s) at various times for station 2

Month	Volume of gas flared (m^3/s)	Discharge Velocity (m/s)	Wind Speed(m^3/s)	Stack Temp.(^0c)
Jan	2.998	14.2	2.20	1000
Feb.	3.035	12.5	2.75	1100
March	3.310	12.5	1.39	900
April	2.024	13.5	1.28	1100
May	5.167	13.0	1.75	1000
June	4.50	13.0	2.0	950
July	4.190	14.0	1.94	900
Aug.	5.116	14.5	1.38	1050
Sept.	5.424	12.0	2.0	1100
Oct.	4.620	12.0	1.38	850
Nov.	4.781	13.5	1.39	900
Dec.	4.980	14.0	2.6	950

5.12 SIMULATION RESULTS

Simulation of the model means the use of computer codes to show the operation and behavior of the system. The model equations were simulated using visual basic programme. The result obtained are presented in the table below ;

RESULTS

Concentration for January Station 1 at 64% Efficiency (Volume = 1.004; Condition = Stable)

Distance	CO2	CO	SO2	NO2	THC
100	0	0	0	0	0
200	42.23197	43.6782	0.027056	0.023342	14.25844
300	1.72E-31	1.78E-31	1.1E-34	9.49E-35	5.8E-32
400	2.1E-100	2.2E-100	1.4E-103	1.2E-103	7.2E-101
500	2.3E-137	2.4E-137	1.5E-140	1.3E-140	7.9E-138
1000	3.1E-104	3.2E-104	2E-107	1.7E-107	1E-104
1500	3.78E-36	3.91E-36	2.42E-39	2.09E-39	1.28E-36
2000	0	0	0	0	0
2500	4.5E-131	4.6E-131	2.9E-134	2.5E-134	1.5E-131
3000	0	0	0	0	0
3500	0	0	0	0	0
4000	0	0	0	0	0
4500	0	0	0	0	0
5000	0	0	0	0	0

Concentration for January Station 1 at 64% Efficiency (Volume = 1.004; Condition = Neutral)

Distance	CO2	CO	SO2	NO2	THC
100	0	0	0	0	0
200	39223.22	40566.42	25.12818	21.67922	13242.62
300	0.000498	0.000515	3.19E-07	2.75E-07	0.000168
400	3.13E-21	3.24E-21	2.01E-24	1.73E-24	1.06E-21
500	1.66E-30	1.71E-30	1.06E-33	9.15E-34	5.59E-31
1000	2.48E-22	2.57E-22	1.59E-25	1.37E-25	8.37E-23
1500	5.06E-06	5.23E-06	3.24E-09	2.8E-09	1.71E-06
2000	0	0	0	0	0
2500	1.47E-29	1.52E-29	9.4E-33	8.11E-33	4.96E-30
3000	0	0	0	0	0
3500	6E-272	6.2E-272	3.9E-275	3.3E-275	2E-272
4000	0	0	0	0	0
4500	0	0	0	0	0
5000	2.5E-161	2.6E-161	1.6E-164	1.4E-164	8.5E-162

Concentration for January Station 1 at 64% Efficiency (Volume = 1.004; Condition = Unstable)

Distance	CO2	CO	SO2	NO2	THC
100	0	0	0	0	0
200	19873.4	20553.96	12.7318	10.9843	6709.693
300	8330.059	8615.32	5.336615	4.604139	2812.41
400	246.8237	255.2762	0.158127	0.136423	83.3331
500	19.98929	20.67382	0.012806	0.011048	6.748822
1000	40.31249	41.69299	0.025826	0.022281	13.61038
1500	31.72886	32.81541	0.020327	0.017537	10.71236
2000	1.6E-59	1.66E-59	1.03E-62	8.85E-63	5.41E-60
2500	0.049162	0.050845	3.15E-05	2.72E-05	0.016598
3000	7.68E-92	7.95E-92	4.92E-95	4.25E-95	2.59E-92
3500	9.38E-27	9.7E-27	6.01E-30	5.18E-30	3.17E-27
4000	1.62E-34	1.67E-34	1.04E-37	8.93E-38	5.46E-35
4500	3.9E-256	4E-256	2.5E-259	2.1E-259	1.3E-256
5000	6.19E-17	6.4E-17	3.97E-20	3.42E-20	2.09E-17

Concentration for February Station 1 at 64% Efficiency (Volume = 0.898; Condition = Stable)

Distance	CO2	CO	SO2	NO2	THC
100	0	0	0	0	0
200	46.44057	48.03092	0.029752	0.025668	15.67935
300	1.84E-31	1.9E-31	1.18E-34	1.02E-34	6.22E-32
400	2.3E-100	2.3E-100	1.4E-103	1.2E-103	7.6E-101
500	2.5E-137	2.6E-137	1.6E-140	1.4E-140	8.5E-138
1000	3.4E-104	3.5E-104	2.2E-107	1.9E-107	1.1E-104
1500	4.28E-36	4.42E-36	2.74E-39	2.36E-39	1.44E-36
2000	0	0	0	0	0
2500	5.1E-131	5.3E-131	3.3E-134	2.8E-134	1.7E-131
3000	0	0	0	0	0
3500	0	0	0	0	0
4000	0	0	0	0	0
4500	0	0	0	0	0
5000	0	0	0	0	0

Concentration for February Station 1 at 64% Efficiency (Volume = 0.898; Condition = Neutral)

Distance	CO2	CO	SO2	NO2	THC
100	0	0	0	0	0
200	44325.9	45843.83	28.39719	24.49954	14965.39
300	0.000559	0.000578	3.58E-07	3.09E-07	0.000189
400	3.51E-21	3.63E-21	2.25E-24	1.94E-24	1.18E-21
500	1.86E-30	1.93E-30	1.19E-33	1.03E-33	6.28E-31
1000	2.8E-22	2.9E-22	1.8E-25	1.55E-25	9.47E-23
1500	5.75E-06	5.95E-06	3.69E-09	3.18E-09	1.94E-06
2000	0	0	0	0	0
2500	1.67E-29	1.73E-29	1.07E-32	9.23E-33	5.64E-30
3000	0	0	0	0	0
3500	6.8E-272	7.1E-272	4.4E-275	3.8E-275	2.3E-272
4000	0	0	0	0	0
4500	0	0	0	0	0
5000	2.9E-161	3E-161	1.8E-164	1.6E-164	9.7E-162

Concentration for February Station 1 at 64% Efficiency (Volume = 0.898; Condition = Unstable)

Distance	CO2	CO	SO2	NO2	THC
100	0	0	0	0	0
200	22620	23394.62	14.49141	12.50239	7637.009
300	9478.121	9802.697	6.072116	5.238688	3200.021
400	280.7761	290.3912	0.179878	0.155189	94.79616
500	22.745	23.5239	0.014571	0.012571	7.67921
1000	45.8847	47.45601	0.029396	0.025361	15.49168
1500	36.11872	37.3556	0.023139	0.019963	12.19447
2000	1.82E-59	1.88E-59	1.17E-62	1.01E-62	6.15E-60
2500	0.055963	0.05788	3.59E-05	3.09E-05	0.018894
3000	8.74E-92	9.04E-92	5.6E-95	4.83E-95	2.95E-92
3500	1.07E-26	1.1E-26	6.84E-30	5.9E-30	3.6E-27
4000	1.84E-34	1.9E-34	1.18E-37	1.02E-37	6.21E-35
4500	4.4E-256	4.6E-256	2.8E-259	2.4E-259	1.5E-256
5000	7.05E-17	7.29E-17	4.51E-20	3.89E-20	2.38E-17

Concentration for March Station 1 at 64% Efficiency (Volume = 0.735; Condition = Stable)

Distance	CO2	CO	SO2	NO2	THC
100	0	0	0	0	0
200	32.16054	33.26187	0.020604	0.017776	10.8581
300	1.34E-31	1.39E-31	8.61E-35	7.43E-35	4.54E-32
400	1.7E-100	1.8E-100	1.1E-103	9.4E-104	5.7E-101
500	1.8E-137	1.9E-137	1.2E-140	1E-140	6.1E-138
1000	2.3E-104	2.4E-104	1.5E-107	1.3E-107	7.9E-105
1500	2.79E-36	2.88E-36	1.79E-39	1.54E-39	9.41E-37
2000	0	0	0	0	0
2500	3.3E-131	3.4E-131	2.1E-134	1.8E-134	1.1E-131
3000	0	0	0	0	0
3500	0	0	0	0	0
4000	0	0	0	0	0
4500	0	0	0	0	0
5000	0	0	0	0	0

Concentration for March Station 1 at 64% Efficiency (Volume = 0.735; Condition = Neutral)

Distance	CO2	CO	SO2	NO2	THC
100	0	0	0	0	0
200	28953.71	29945.23	18.54907	16.00312	9775.407
300	0.00037	0.000382	2.37E-07	2.04E-07	0.000125
400	2.33E-21	2.41E-21	1.49E-24	1.29E-24	7.88E-22
500	1.23E-30	1.27E-30	7.88E-34	6.8E-34	4.15E-31
1000	1.83E-22	1.89E-22	1.17E-25	1.01E-25	6.18E-23
1500	3.71E-06	3.84E-06	2.38E-09	2.05E-09	1.25E-06
2000	0	0	0	0	0
2500	1.08E-29	1.11E-29	6.89E-33	5.95E-33	3.63E-30
3000	0	0	0	0	0
3500	4.4E-272	4.6E-272	2.8E-275	2.4E-275	1.5E-272
4000	0	0	0	0	0
4500	0	0	0	0	0
5000	1.8E-161	1.9E-161	1.2E-164	1E-164	6.2E-162

Concentration for March Station 1 at 64% Efficiency (Volume = 0.735; Condition = Unstable)

Distance	CO2	CO	SO2	NO2	THC
100	0	0	0	0	0
200	14550.94	15049.24	9.321996	8.042507	4912.716
300	6101.464	6310.407	3.908876	3.372363	2059.988
400	180.8373	187.03	0.115853	0.099951	61.05463
500	14.64087	15.14225	0.00938	0.008092	4.94308
1000	29.51549	30.52625	0.018909	0.016314	9.965076
1500	23.22781	24.02324	0.014881	0.012838	7.842218
2000	1.17E-59	1.21E-59	7.52E-63	6.49E-63	3.96E-60
2500	0.03599	0.037222	2.31E-05	1.99E-05	0.012151
3000	5.63E-92	5.82E-92	3.6E-95	3.11E-95	1.9E-92
3500	6.87E-27	7.1E-27	4.4E-30	3.79E-30	2.32E-27
4000	1.18E-34	1.22E-34	7.58E-38	6.54E-38	3.99E-35
4500	2.8E-256	2.9E-256	1.8E-259	1.6E-259	9.6E-257
5000	4.53E-17	4.69E-17	2.9E-20	2.5E-20	1.53E-17

Concentration for April Station 1 at 64% Efficiency (Volume = 0.706; Condition = Stable)

Distance	CO2	CO	SO2	NO2	THC
100	0	0	0	0	0
200	54.9537	56.83558	0.035206	0.030374	18.55357
300	2.1E-31	2.18E-31	1.35E-34	1.16E-34	7.1E-32
400	2.5E-100	2.6E-100	1.6E-103	1.4E-103	8.5E-101
500	2.9E-137	3E-137	1.8E-140	1.6E-140	9.7E-138
1000	4E-104	4.2E-104	2.6E-107	2.2E-107	1.4E-104
1500	5.27E-36	5.45E-36	3.38E-39	2.91E-39	1.78E-36
2000	0	0	0	0	0
2500	6.3E-131	6.5E-131	4E-134	3.5E-134	2.1E-131
3000	0	0	0	0	0
3500	0	0	0	0	0
4000	0	0	0	0	0
4500	0	0	0	0	0
5000	0	0	0	0	0

Concentration for April Station 1 at 64% Efficiency (Volume = 0.706; Condition = Neutral)

Distance	CO2	CO	SO2	NO2	THC
100	0	0	0	0	0
200	54575.13	56444.05	34.96332	30.16443	18425.76
300	0.000683	0.000706	4.38E-07	3.78E-07	0.000231
400	4.27E-21	4.41E-21	2.73E-24	2.36E-24	1.44E-21
500	2.27E-30	2.35E-30	1.46E-33	1.26E-33	7.68E-31
1000	3.45E-22	3.57E-22	2.21E-25	1.91E-25	1.17E-22
1500	7.15E-06	7.39E-06	4.58E-09	3.95E-09	2.41E-06
2000	0	0	0	0	0
2500	2.07E-29	2.15E-29	1.33E-32	1.15E-32	7E-30
3000	0	0	0	0	0
3500	8.5E-272	8.8E-272	5.4E-275	4.7E-275	2.9E-272
4000	0	0	0	0	0
4500	0	0	0	0	0
5000	3.6E-161	3.7E-161	2.3E-164	2E-164	1.2E-161

Concentration for April Station 1 at 64% Efficiency (Volume = 0.706; Condition = Unstable)

Distance	CO2	CO	SO2	NO2	THC
100	0	0	0	0	0
200	28141.39	29105.09	18.02866	15.55414	9501.15
300	11785.89	12189.49	7.550576	6.514222	3979.173
400	349.0225	360.9747	0.2236	0.19291	117.8376
500	28.28439	29.25298	0.01812	0.015633	9.549429
1000	57.08629	59.04119	0.036572	0.031552	19.27358
1500	44.94365	46.48273	0.028793	0.024841	15.17396
2000	2.26E-59	2.34E-59	1.45E-62	1.25E-62	7.65E-60
2500	0.069637	0.072022	4.46E-05	3.85E-05	0.023511
3000	1.09E-91	1.12E-91	6.97E-95	6.01E-95	3.67E-92
3500	1.33E-26	1.37E-26	8.51E-30	7.34E-30	4.48E-27
4000	2.29E-34	2.37E-34	1.47E-37	1.27E-37	7.73E-35
4500	5.5E-256	5.7E-256	3.5E-259	3E-259	1.8E-256
5000	8.77E-17	9.07E-17	5.62E-20	4.85E-20	2.96E-17

Concentration for May Station 1 at 64% Efficiency (Volume = 0.909; Condition = Stable)

Distance	CO2	CO	SO2	NO2	THC
100	0	0	0	0	0
200	46.69944	48.29865	0.029918	0.025811	15.76675
300	1.84E-31	1.91E-31	1.18E-34	1.02E-34	6.22E-32
400	2.3E-100	2.3E-100	1.4E-103	1.2E-103	7.6E-101
500	2.5E-137	2.6E-137	1.6E-140	1.4E-140	8.5E-138
1000	3.4E-104	3.5E-104	2.2E-107	1.9E-107	1.2E-104
1500	4.32E-36	4.47E-36	2.77E-39	2.39E-39	1.46E-36
2000	0	0	0	0	0
2500	5.1E-131	5.3E-131	3.3E-134	2.8E-134	1.7E-131
3000	0	0	0	0	0
3500	0	0	0	0	0
4000	0	0	0	0	0
4500	0	0	0	0	0
5000	0	0	0	0	0

Concentration for May Station 1 at 64% Efficiency (Volume = 0.909; Condition = Neutral)

Distance	CO2	CO	SO2	NO2	THC
100	0	0	0	0	0
200	44806.39	46340.78	28.70501	24.76511	15127.62
300	0.000565	0.000584	3.62E-07	3.12E-07	0.000191
400	3.54E-21	3.66E-21	2.27E-24	1.96E-24	1.2E-21
500	1.88E-30	1.94E-30	1.2E-33	1.04E-33	6.35E-31
1000	2.83E-22	2.93E-22	1.82E-25	1.57E-25	9.57E-23
1500	5.82E-06	6.02E-06	3.73E-09	3.22E-09	1.97E-06
2000	0	0	0	0	0
2500	1.69E-29	1.75E-29	1.08E-32	9.34E-33	5.7E-30
3000	0	0	0	0	0
3500	6.9E-272	7.2E-272	4.4E-275	3.8E-275	2.3E-272
4000	0	0	0	0	0
4500	0	0	0	0	0
5000	2.9E-161	3E-161	1.9E-164	1.6E-164	9.8E-162

Concentration for May Station 1 at 64% Efficiency (Volume = 0.909; Condition = Unstable)

Distance	CO2	CO	SO2	NO2	THC
100	0	0	0	0	0
200	22896.51	23680.6	14.66855	12.65522	7730.363
300	9593.361	9921.884	6.145944	5.302383	3238.929
400	284.1773	293.9089	0.182057	0.157069	95.94448
500	23.02169	23.81007	0.014749	0.012724	7.772627
1000	46.44574	48.03627	0.029755	0.025671	15.6811
1500	36.56115	37.81318	0.023423	0.020208	12.34384
2000	1.84E-59	1.91E-59	1.18E-62	1.02E-62	6.23E-60
2500	0.056649	0.058589	3.63E-05	3.13E-05	0.019126
3000	8.85E-92	9.15E-92	5.67E-95	4.89E-95	2.99E-92
3500	1.08E-26	1.12E-26	6.92E-30	5.97E-30	3.65E-27
4000	1.86E-34	1.93E-34	1.19E-37	1.03E-37	6.29E-35
4500	4.5E-256	4.6E-256	2.9E-259	2.5E-259	1.5E-256
5000	7.13E-17	7.38E-17	4.57E-20	3.94E-20	2.41E-17

Concentration for June Station 1 at 64% Efficiency (Volume = 0.86; Condition = Stable)

Distance	CO2	CO	SO2	NO2	THC
100	0	0	0	0	0
200	52.69271	54.49717	0.033757	0.029124	17.79021
300	2.05E-31	2.12E-31	1.31E-34	1.13E-34	6.93E-32
400	2.5E-100	2.6E-100	1.6E-103	1.4E-103	8.4E-101
500	2.8E-137	2.9E-137	1.8E-140	1.5E-140	9.4E-138
1000	3.9E-104	4E-104	2.5E-107	2.1E-107	1.3E-104
1500	4.95E-36	5.12E-36	3.17E-39	2.74E-39	1.67E-36
2000	0	0	0	0	0
2500	5.9E-131	6.1E-131	3.8E-134	3.3E-134	2E-131
3000	0	0	0	0	0
3500	0	0	0	0	0
4000	0	0	0	0	0
4500	0	0	0	0	0
5000	0	0	0	0	0

Concentration for June Station 1 at 64% Efficiency (Volume = 0.86; Condition = Neutral)

Distance	CO2	CO	SO2	NO2	THC
100	0	0	0	0	0
200	51319.6	53077.03	32.87767	28.36505	17326.62
300	0.000645	0.000667	4.13E-07	3.56E-07	0.000218
400	4.04E-21	4.17E-21	2.59E-24	2.23E-24	1.36E-21
500	2.15E-30	2.22E-30	1.38E-33	1.19E-33	7.25E-31
1000	3.25E-22	3.36E-22	2.08E-25	1.8E-25	1.1E-22
1500	6.69E-06	6.92E-06	4.29E-09	3.7E-09	2.26E-06
2000	0	0	0	0	0
2500	1.94E-29	2.01E-29	1.24E-32	1.07E-32	6.56E-30
3000	0	0	0	0	0
3500	7.9E-272	8.2E-272	5.1E-275	4.4E-275	2.7E-272
4000	0	0	0	0	0
4500	0	0	0	0	0
5000	3.3E-161	3.5E-161	2.1E-164	1.8E-164	1.1E-161

Concentration for June Station 1 at 64% Efficiency (Volume = 0.86; Condition = Unstable)

Distance	CO2	CO	SO2	NO2	THC
100	0	0	0	0	0
200	26327.92	27229.51	16.86686	14.5518	8888.881
300	11029.04	11406.73	7.065705	6.095903	3723.645
400	326.6637	337.8503	0.209276	0.180552	110.2888
500	26.46744	27.37382	0.016956	0.014629	8.935989
1000	53.40689	55.2358	0.034215	0.029519	18.03133
1500	42.04346	43.48323	0.026935	0.023238	14.19479
2000	2.12E-59	2.19E-59	1.36E-62	1.17E-62	7.16E-60
2500	0.065143	0.067374	4.17E-05	3.6E-05	0.021994
3000	1.02E-91	1.05E-91	6.52E-95	5.62E-95	3.44E-92
3500	1.24E-26	1.29E-26	7.96E-30	6.87E-30	4.2E-27
4000	2.14E-34	2.21E-34	1.37E-37	1.18E-37	7.23E-35
4500	5.1E-256	5.3E-256	3.3E-259	2.8E-259	1.7E-256
5000	8.2E-17	8.48E-17	5.25E-20	4.53E-20	2.77E-17

Concentration for January Station 2 at 64% Efficiency (Volume = 2.998; Condition = Stable)

Distance	CO2	CO	SO2	NO2	THC
100	0	0	0	0	0
200	117.3143	121.3317	0.075157	0.064841	39.60787
300	3.82E-31	3.95E-31	2.45E-34	2.11E-34	1.29E-31
400	4.2E-100	4.4E-100	2.7E-103	2.3E-103	1.4E-100
500	5.3E-137	5.5E-137	3.4E-140	2.9E-140	1.8E-137
1000	8.7E-104	9E-104	5.6E-107	4.8E-107	2.9E-104
1500	1.36E-35	1.4E-35	8.69E-39	7.5E-39	4.58E-36
2000	0	0	0	0	0
2500	1.6E-130	1.7E-130	1E-133	9E-134	5.5E-131
3000	0	0	0	0	0
3500	0	0	0	0	0
4000	0	0	0	0	0
4500	0	0	0	0	0
5000	0	0	0	0	0

Concentration for January Station 2 at 64% Efficiency (Volume = 2.998; Condition = Neutral)

Distance	CO2	CO	SO2	NO2	THC
100	0	0	0	0	0
200	139542.9	144321.6	89.39757	77.12732	47112.75
300	0.001683	0.00174	1.08E-06	9.3E-07	0.000568
400	1.03E-20	1.07E-20	6.61E-24	5.7E-24	3.48E-21
500	5.62E-30	5.81E-30	3.6E-33	3.11E-33	1.9E-30
1000	8.86E-22	9.16E-22	5.68E-25	4.9E-25	2.99E-22
1500	1.9E-05	1.97E-05	1.22E-08	1.05E-08	6.43E-06
2000	0	0	0	0	0
2500	5.53E-29	5.72E-29	3.54E-32	3.06E-32	1.87E-29
3000	0	0	0	0	0
3500	2.2E-271	2.3E-271	1.4E-274	1.2E-274	7.6E-272
4000	0	0	0	0	0
4500	0	0	0	0	0
5000	9.5E-161	9.8E-161	6.1E-164	5.3E-164	3.2E-161

Concentration for January Station 2 at 64% Efficiency (Volume = 2.998; Condition = Unstable)

Distance	CO2	CO	SO2	NO2	THC
100	0	0	0	0	0
200	75437.2	78020.54	48.32851	41.69518	25469.25
300	31523.51	32603.03	20.1954	17.42348	10643.03
400	932.0919	964.0112	0.597141	0.51518	314.6946
500	75.66831	78.25956	0.048477	0.041823	25.54728
1000	153.046	158.287	0.098048	0.084591	51.67168
1500	120.5831	124.7124	0.077251	0.066648	40.71148
2000	6.05E-59	6.26E-59	3.87E-62	3.34E-62	2.04E-59
2500	0.186835	0.193234	0.00012	0.000103	0.06308
3000	2.91E-91	3.01E-91	1.87E-94	1.61E-94	9.84E-92
3500	3.56E-26	3.69E-26	2.28E-29	1.97E-29	1.2E-26
4000	6.14E-34	6.35E-34	3.93E-37	3.39E-37	2.07E-34
4500	1.5E-255	1.5E-255	9.4E-259	8.1E-259	5E-256
5000	2.35E-16	2.43E-16	1.51E-19	1.3E-19	7.94E-17

Concentration for February Station 2 at 64% Efficiency (Volume = 3.038; Condition = Stable)

Distance	CO2	CO	SO2	NO2	THC
100	0	0	0	0	0
200	101.6652	105.1467	0.065131	0.056192	34.32439
300	3.47E-31	3.59E-31	2.22E-34	1.92E-34	1.17E-31
400	3.9E-100	4.1E-100	2.5E-103	2.2E-103	1.3E-100
500	4.8E-137	4.9E-137	3.1E-140	2.6E-140	1.6E-137
1000	7.5E-104	7.8E-104	4.8E-107	4.2E-107	2.5E-104
1500	1.11E-35	1.15E-35	7.13E-39	6.16E-39	3.76E-36
2000	0	0	0	0	0
2500	1.3E-130	1.4E-130	8.5E-134	7.4E-134	4.5E-131
3000	0	0	0	0	0
3500	0	0	0	0	0
4000	0	0	0	0	0
4500	0	0	0	0	0
5000	0	0	0	0	0

Concentration for February Station 2 at 64% Efficiency (Volume = 3.038; Condition = Neutral)

Distance	CO2	CO	SO2	NO2	THC
100	0	0	0	0	0
200	114724.6	118653.3	73.49778	63.40985	38733.52
300	0.001398	0.001446	8.96E-07	7.73E-07	0.000472
400	8.62E-21	8.91E-21	5.52E-24	4.76E-24	2.91E-21
500	4.67E-30	4.83E-30	2.99E-33	2.58E-33	1.58E-30
1000	7.28E-22	7.53E-22	4.66E-25	4.02E-25	2.46E-22
1500	1.55E-05	1.6E-05	9.91E-09	8.55E-09	5.22E-06
2000	0	0	0	0	0
2500	4.49E-29	4.65E-29	2.88E-32	2.48E-32	1.52E-29
3000	0	0	0	0	0
3500	1.8E-271	1.9E-271	1.2E-274	1E-274	6.2E-272
4000	0	0	0	0	0
4500	0	0	0	0	0
5000	7.7E-161	8E-161	4.9E-164	4.3E-164	2.6E-161

Concentration for February Station 2 at 64% Efficiency (Volume = 3.038; Condition = Unstable)

Distance	CO2	CO	SO2	NO2	THC
100	0	0	0	0	0
200	61170.54	63265.32	39.18864	33.80981	20652.51
300	25578.43	26454.36	16.38671	14.13755	8635.837
400	756.6459	782.5571	0.484742	0.418209	255.4602
500	61.39395	63.49637	0.039332	0.033933	20.72794
1000	124.0978	128.3475	0.079503	0.068591	41.89814
1500	97.75359	101.1011	0.062625	0.05403	33.00375
2000	4.91E-59	5.08E-59	3.15E-62	2.71E-62	1.66E-59
2500	0.151463	0.156649	9.7E-05	8.37E-05	0.051137
3000	2.36E-91	2.44E-91	1.51E-94	1.31E-94	7.98E-92
3500	2.89E-26	2.99E-26	1.85E-29	1.6E-29	9.75E-27
4000	4.98E-34	5.15E-34	3.19E-37	2.75E-37	1.68E-34
4500	1.2E-255	1.2E-255	7.6E-259	6.6E-259	4E-256
5000	1.91E-16	1.97E-16	1.22E-19	1.05E-19	6.44E-17

Concentration for March Station 2 at 64% Efficiency (Volume = 3.31; Condition = Stable)

Distance	CO2	CO	SO2	NO2	THC
100	0	0	0	0	0
200	148.3628	153.4435	0.095048	0.082002	50.09054
300	3.76E-31	3.89E-31	2.41E-34	2.08E-34	1.27E-31
400	3.7E-100	3.8E-100	2.4E-103	2E-103	1.2E-100
500	5.3E-137	5.5E-137	3.4E-140	2.9E-140	1.8E-137
1000	1.1E-103	1.2E-103	7.2E-107	6.2E-107	3.8E-104
1500	2.29E-35	2.37E-35	1.47E-38	1.27E-38	7.73E-36
2000	0	0	0	0	0
2500	2.8E-130	2.9E-130	1.8E-133	1.5E-133	9.3E-131
3000	0	0	0	0	0
3500	0	0	0	0	0
4000	0	0	0	0	0
4500	0	0	0	0	0
5000	0	0	0	0	0

Concentration for March Station 2 at 64% Efficiency (Volume = 3.31; Condition = Neutral)

Distance	CO2	CO	SO2	NO2	THC
100	0	0	0	0	0
200	233102.5	241085	149.3361	128.839	78700.49
300	0.002654	0.002745	1.7E-06	1.47E-06	0.000896
400	1.58E-20	1.63E-20	1.01E-23	8.73E-24	5.33E-21
500	8.9E-30	9.21E-30	5.7E-33	4.92E-33	3.01E-30
1000	1.49E-21	1.54E-21	9.52E-25	8.21E-25	5.02E-22
1500	3.39E-05	3.51E-05	2.17E-08	1.87E-08	1.14E-05
2000	0	0	0	0	0
2500	9.86E-29	1.02E-28	6.32E-32	5.45E-32	3.33E-29
3000	0	0	0	0	0
3500	3.9E-271	4.1E-271	2.5E-274	2.2E-274	1.3E-271
4000	0	0	0	0	0
4500	0	0	0	0	0
5000	1.7E-160	1.8E-160	1.1E-163	9.4E-164	5.7E-161

Concentration for March Station 2 at 64% Efficiency (Volume = 3.31; Condition = Unstable)

Distance	CO2	CO	SO2	NO2	THC
100	0	0	0	0	0
200	135545.8	140187.6	86.83685	74.91806	45763.25
300	56447.24	58380.27	36.16268	31.19917	19057.83
400	1665.091	1722.112	1.066733	0.920319	562.1711
500	135.5403	140.1819	0.086833	0.074915	45.76138
1000	275.0426	284.4614	0.176205	0.15202	92.86042
1500	216.9551	224.3847	0.138991	0.119914	73.2488
2000	1.08E-58	1.12E-58	6.92E-62	5.97E-62	3.65E-59
2500	0.336158	0.34767	0.000215	0.000186	0.113494
3000	5.23E-91	5.41E-91	3.35E-94	2.89E-94	1.77E-91
3500	6.41E-26	6.63E-26	4.11E-29	3.54E-29	2.16E-26
4000	1.11E-33	1.14E-33	7.08E-37	6.11E-37	3.73E-34
4500	2.6E-255	2.7E-255	1.7E-258	1.5E-258	8.9E-256
5000	4.23E-16	4.38E-16	2.71E-19	2.34E-19	1.43E-16

Concentration for April Station 2 at 64% Efficiency (Volume = 7.024; Condition = Stable)

Distance	CO2	CO	SO2	NO2	THC
100	0	0	0	0	0
200	149.9167	155.0506	0.096043	0.082861	50.61517
300	2.16E-31	2.23E-31	1.38E-34	1.19E-34	7.29E-32
400	1.6E-100	1.6E-100	1E-103	8.7E-104	5.3E-101
500	3.2E-137	3.3E-137	2E-140	1.8E-140	1.1E-137
1000	1.2E-103	1.2E-103	7.6E-107	6.5E-107	4E-104
1500	4.43E-35	4.59E-35	2.84E-38	2.45E-38	1.5E-35
2000	0	0	0	0	0
2500	5.4E-130	5.6E-130	3.5E-133	3E-133	1.8E-130
3000	0	0	0	0	0
3500	0	0	0	0	0
4000	0	0	0	0	0
4500	0	0	0	0	0
5000	0	0	0	0	0

Concentration for April Station 2 at 64% Efficiency (Volume = 7.024; Condition = Neutral)

Distance	CO2	CO	SO2	NO2	THC
100	0	0	0	0	0
200	441258.2	456369	282.6901	243.8895	148978.4
300	0.004413	0.004564	2.83E-06	2.44E-06	0.00149
400	2.46E-20	2.54E-20	1.57E-23	1.36E-23	8.3E-21
500	1.5E-29	1.55E-29	9.59E-33	8.27E-33	5.05E-30
1000	2.84E-21	2.94E-21	1.82E-24	1.57E-24	9.59E-22
1500	7.41E-05	7.66E-05	4.75E-08	4.09E-08	2.5E-05
2000	0	0	0	0	0
2500	2.16E-28	2.24E-28	1.38E-31	1.19E-31	7.3E-29
3000	0	0	0	0	0
3500	8.3E-271	8.6E-271	5.3E-274	4.6E-274	2.8E-271
4000	0	0	0	0	0
4500	0	0	0	0	0
5000	3.7E-160	3.8E-160	2.4E-163	2.1E-163	1.3E-160

Concentration for April Station 2 at 64% Efficiency (Volume = 7.024; Condition = Unstable)

Distance	CO2	CO	SO2	NO2	THC
100	0	0	0	0	0
200	302446	312803.2	193.7607	167.1661	102112.4
300	124979.2	129259.1	80.06739	69.07775	42195.72
400	3667.011	3792.588	2.349255	2.026808	1238.063
500	300.3265	310.6111	0.192403	0.165995	101.3968
1000	613.9546	634.9793	0.393327	0.339341	207.2845
1500	485.564	502.192	0.311074	0.268378	163.937
2000	2.38E-58	2.46E-58	1.53E-61	1.32E-61	8.04E-59
2500	0.752353	0.778117	0.000482	0.000416	0.254011
3000	1.16E-90	1.2E-90	7.46E-94	6.44E-94	3.93E-91
3500	1.43E-25	1.48E-25	9.19E-29	7.93E-29	4.84E-26
4000	2.47E-33	2.56E-33	1.58E-36	1.37E-36	8.35E-34
4500	5.9E-255	6.1E-255	3.8E-258	3.2E-258	2E-255
5000	9.47E-16	9.8E-16	6.07E-19	5.24E-19	3.2E-16

Concentration for May Station 2 at 64% Efficiency (Volume = 5.162; Condition = Stable)

Distance	CO2	CO	SO2	NO2	THC
100	0	0	0	0	0
200	166.4048	172.1033	0.106606	0.091974	56.1819
300	4.01E-31	4.15E-31	2.57E-34	2.22E-34	1.35E-31
400	3.8E-100	3.9E-100	2.4E-103	2.1E-103	1.3E-100
500	5.7E-137	5.9E-137	3.6E-140	3.1E-140	1.9E-137
1000	1.3E-103	1.3E-103	8.1E-107	7E-107	4.3E-104
1500	2.72E-35	2.81E-35	1.74E-38	1.5E-38	9.18E-36
2000	0	0	0	0	0
2500	3.3E-130	3.4E-130	2.1E-133	1.8E-133	1.1E-130
3000	0	0	0	0	0
3500	0	0	0	0	0
4000	0	0	0	0	0
4500	0	0	0	0	0
5000	0	0	0	0	0

Concentration for May Station 2 at 64% Efficiency (Volume = 5.162; Condition = Neutral)

Distance	CO2	CO	SO2	NO2	THC
100	0	0	0	0	0
200	276325.3	285788	177.0266	152.7288	93293.46
300	0.00311	0.003217	1.99E-06	1.72E-06	0.00105
400	1.84E-20	1.9E-20	1.18E-23	1.02E-23	6.21E-21
500	1.04E-29	1.08E-29	6.69E-33	5.77E-33	3.53E-30
1000	1.76E-21	1.82E-21	1.13E-24	9.75E-25	5.95E-22
1500	4.07E-05	4.21E-05	2.61E-08	2.25E-08	1.37E-05
2000	0	0	0	0	0
2500	1.18E-28	1.23E-28	7.59E-32	6.55E-32	4E-29
3000	0	0	0	0	0
3500	4.7E-271	4.9E-271	3E-274	2.6E-274	1.6E-271
4000	0	0	0	0	0
4500	0	0	0	0	0
5000	2E-160	2.1E-160	1.3E-163	1.1E-163	6.9E-161

Concentration for May Station 2 at 64% Efficiency (Volume = 5.162; Condition = Unstable)

Distance	CO2	CO	SO2	NO2	THC
100	0	0	0	0	0
200	163025.6	168608.3	104.4416	90.10648	55041
300	67844.62	70167.95	43.46436	37.49866	22905.83
400	2000.35	2068.852	1.281516	1.105621	675.3621
500	162.9185	168.4976	0.104373	0.090047	55.00484
1000	330.8148	342.1435	0.211935	0.182846	111.6903
1500	261.0089	269.9471	0.167214	0.144263	88.12231
2000	1.3E-58	1.34E-58	8.32E-62	7.18E-62	4.38E-59
2500	0.404417	0.418266	0.000259	0.000224	0.13654
3000	6.29E-91	6.51E-91	4.03E-94	3.48E-94	2.12E-91
3500	7.71E-26	7.98E-26	4.94E-29	4.26E-29	2.6E-26
4000	1.33E-33	1.37E-33	8.52E-37	7.35E-37	4.49E-34
4500	3.2E-255	3.3E-255	2E-258	1.7E-258	1.1E-255
5000	5.09E-16	5.27E-16	3.26E-19	2.81E-19	1.72E-16

Concentration for June Station 2 at 64% Efficiency (Volume = 4.5; Condition = Stable)

Distance	CO2	CO	SO2	NO2	THC
100	0	0	0	0	0
200	155.5535	160.8804	0.099655	0.085977	52.51825
300	4.33E-31	4.48E-31	2.78E-34	2.39E-34	1.46E-31
400	4.4E-100	4.6E-100	2.8E-103	2.5E-103	1.5E-100
500	6.1E-137	6.3E-137	3.9E-140	3.3E-140	2E-137
1000	1.2E-103	1.2E-103	7.5E-107	6.5E-107	3.9E-104
1500	2.15E-35	2.23E-35	1.38E-38	1.19E-38	7.27E-36
2000	0	0	0	0	0
2500	2.6E-130	2.7E-130	1.7E-133	1.4E-133	8.7E-131
3000	0	0	0	0	0
3500	0	0	0	0	0
4000	0	0	0	0	0
4500	0	0	0	0	0
5000	0	0	0	0	0

Concentration for June Station 2 at 64% Efficiency (Volume = 4.5; Condition = Neutral)

Distance	CO2	CO	SO2	NO2	THC
100	0	0	0	0	0
200	219999.8	227533.6	140.9419	121.5969	74276.73
300	0.00256	0.002647	1.64E-06	1.41E-06	0.000864
400	1.54E-20	1.59E-20	9.87E-24	8.51E-24	5.2E-21
500	8.57E-30	8.87E-30	5.49E-33	4.74E-33	2.89E-30
1000	1.4E-21	1.45E-21	8.97E-25	7.74E-25	4.73E-22
1500	3.12E-05	3.23E-05	2E-08	1.73E-08	1.05E-05
2000	0	0	0	0	0
2500	9.08E-29	9.39E-29	5.82E-32	5.02E-32	3.07E-29
3000	0	0	0	0	0
3500	3.6E-271	3.8E-271	2.3E-274	2E-274	1.2E-271
4000	0	0	0	0	0
4500	0	0	0	0	0
5000	1.6E-160	1.6E-160	1E-163	8.6E-164	5.3E-161

Concentration for June Station 2 at 64% Efficiency (Volume = 4.5; Condition = Unstable)

Distance	CO2	CO	SO2	NO2	THC
100	0	0	0	0	0
200	124450.2	128711.9	79.72845	68.78533	42017.1
300	51893.87	53670.97	33.24558	28.68246	17520.51
400	1532.146	1584.614	0.981563	0.846838	517.286
500	124.591	128.8575	0.079819	0.068863	42.06463
1000	252.5108	261.158	0.16177	0.139566	85.25319
1500	199.0943	205.9122	0.127549	0.110042	67.21859
2000	9.94E-59	1.03E-58	6.37E-62	5.5E-62	3.36E-59
2500	0.308484	0.319048	0.000198	0.000171	0.104151
3000	4.8E-91	4.97E-91	3.08E-94	2.66E-94	1.62E-91
3500	5.88E-26	6.09E-26	3.77E-29	3.25E-29	1.99E-26
4000	1.01E-33	1.05E-33	6.5E-37	5.6E-37	3.42E-34
4500	2.4E-255	2.5E-255	1.5E-258	1.3E-258	8.2E-256
5000	3.88E-16	4.02E-16	2.49E-19	2.15E-19	1.31E-16

5.2 DISCUSSION OF THE RESULT

The operation of gas plant and flow station in the Niger-Delta area of Nigeria involves flaring of excess gas on twenty-four hourly basis. Combustion of gas flare contributes to the atmosphere content of carbon, Nitrogen, Sulphur and total hydrocarbon. Most pollutant is emitted into the atmosphere from elevated source such as chimney stack and transported through the atmosphere by wind currents from their point of release to downwind receptor. The major meteorological parameter controlling atmospheric dispersion are atmospheric stability and wind speed. One of the major issues in Nigeria is the flaring of gas that is produced with oil in Niger-Delta area. The flaring of gas has been an integral part of the operation associated with exploration of crude oil and natural resources in Nigeria since inception. Flaring of gas has been as a result that most of Nigerians oil facilities were built in 1960s and 1970s. This implies that they were built to environmental standard of those days. Gas flaring has exposed the people of Niger-Delta area to a lot of hazards.

From experiment results shown in Tables 5.11 and 5.12, it could be observed that the volume of gas flare varies from station to station and month. This could be attributed to the fact that the production rate and well properties are not constant for all stations. The simulation results of the predictive model are presented in Table 5.13 - 5.48 . It could be observed from the table that the most dangerous Zone is within 200 – 1500m radius from flare station (Fig 2-12). However, effect of gas flared are felt within the radius range of 2000m away from the flaring source depending on the volume of gas flare, wind speed, surrounding temperature, velocity of discharge and height of stack. It could be observed from the result that the concentration of pollutant in the ground level increases as the volume of gas flare increases. This implies that the concentration of the pollutant is directly proportional to the gas flare.

From the predictive model, it shows that cross wind distance across the x-axis affect the concentration of the pollutant at the ground level, the further the distance, the lesser the concentration of the pollutants. This could be attributed to the fact that the pollutants are engaged in other reaction due to dispersion of pollutants and other component (Unstable atmospheric condition).

But for stable and neutral atmospheric condition, it was observed that the most dangerous zone is within the radius of 200m away from the source. It could also be observed that the effect of gas flared will not be much on the radius of 300m and above from the source. This is as a result of stability of the atmospheric condition. Also, the dispersion and obtained values shows that the model to a large extent conform to the modifies principles by Gaussian.

It was also observed that at 1000m and above, there was a fluctuation on ground level concentration, though the concentration are negligible, this is as a result of pollutant undergo certain reaction with certain component. Also from the (fig2 -12), at 1000m and above, no ground level-concentration.

5.3 CONCLUSION

From the research the following conclusion can be drawn;

1. It was observed that the result of the simulation of model developed based on the modified principles of gas dispersion showed a remarkable agreement with dispersion pattern.
2. The dispersion pattern of pollutant showed that the concentration of pollutants from the flare source depends on the volume of gas flared, height of stack and wind speed.
3. Model equation that represent ground level concentration of pollutants are;

$$C_{co} = \frac{0.01235 E_s \rho v}{2\pi U \delta_y \delta_z} e^{-\left(y^2 / 2\delta_z^2 \right) - \left(He^2 / 2\delta_z^2 \right)}$$

$$C_{co} = \frac{7.55 \times 10^{-3} E_s \rho v}{2\pi U \delta_y \delta_z} e^{-\left(y^2 / 2\delta_z^2 \right) - \left(He^2 / 2\delta_z^2 \right)}$$

$$C_{No_2} = \frac{4.4 \times 10^{-6} E_s \rho v}{2\pi U \delta_y \delta_z} e^{-\left(y^2 / 2\delta_z^2 \right) - \left(He^2 / 2\delta_z^2 \right)}$$

$$C_{THC} = \frac{0.99 - 0.00845 E_s \rho v}{2\pi U \delta_y \delta_z} e^{-\left(y^2 / 2\delta_z^2 \right) - \left(He^2 / 2\delta_z^2 \right)}$$

$$C_{So_2} = \frac{3.06 \times 10^{-6} E_s \rho v}{2\pi U \delta_y \delta_z} e^{-\left(y^2 / 2\delta_z^2 \right) - \left(He^2 / 2\delta_z^2 \right)}$$

5.4 RECOMMENDATION

Though the computer simulation of the model is quite good, the model can be improved upon. The model can be used to evaluate environmental regulations, determining the distance from the flare station where human can inhabit. Although the model was developed for gas flaring, it can be improved upon so as cover other source of environmental pollution in gaseous state e.g. automobile exhaust pollution.

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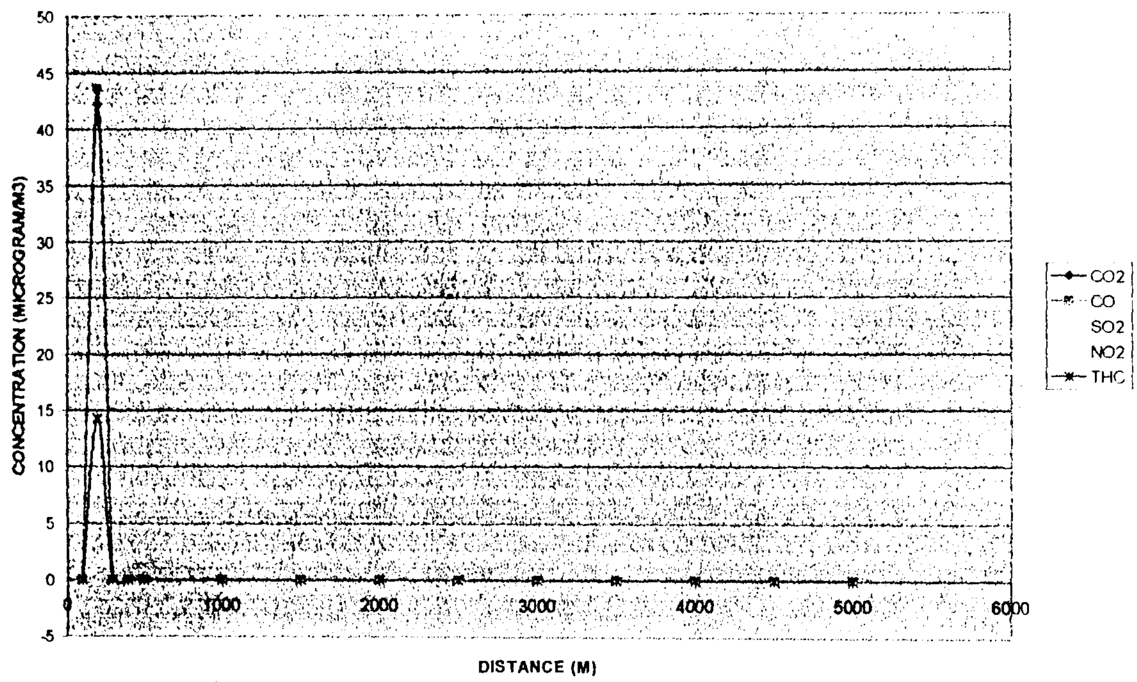
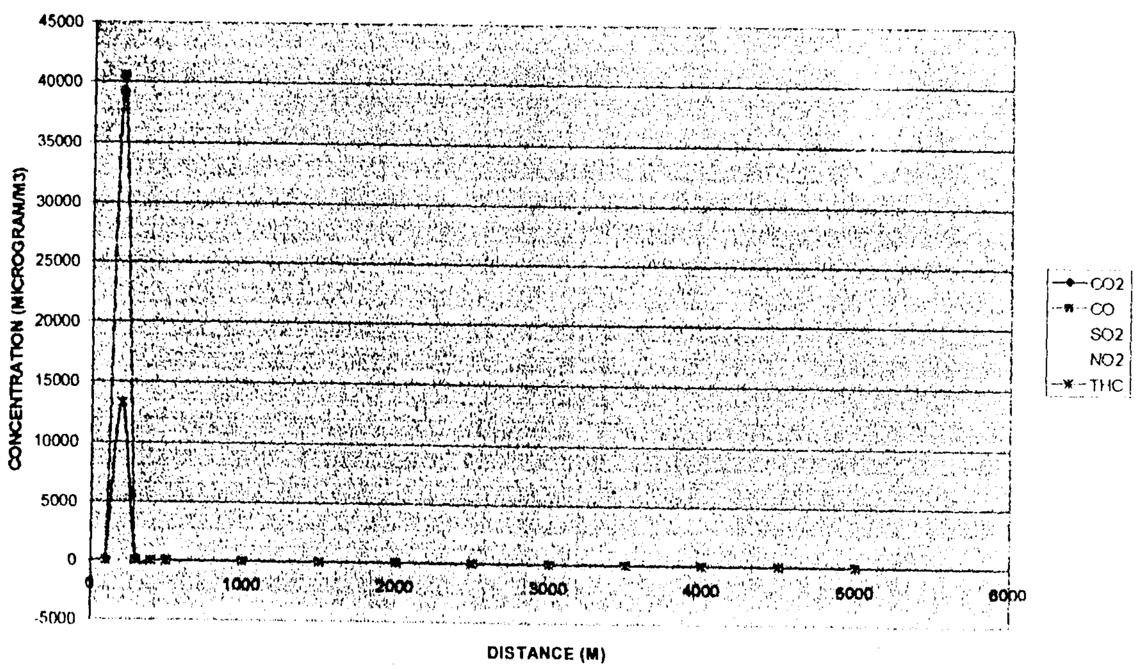
APPENDIX A GRAPH

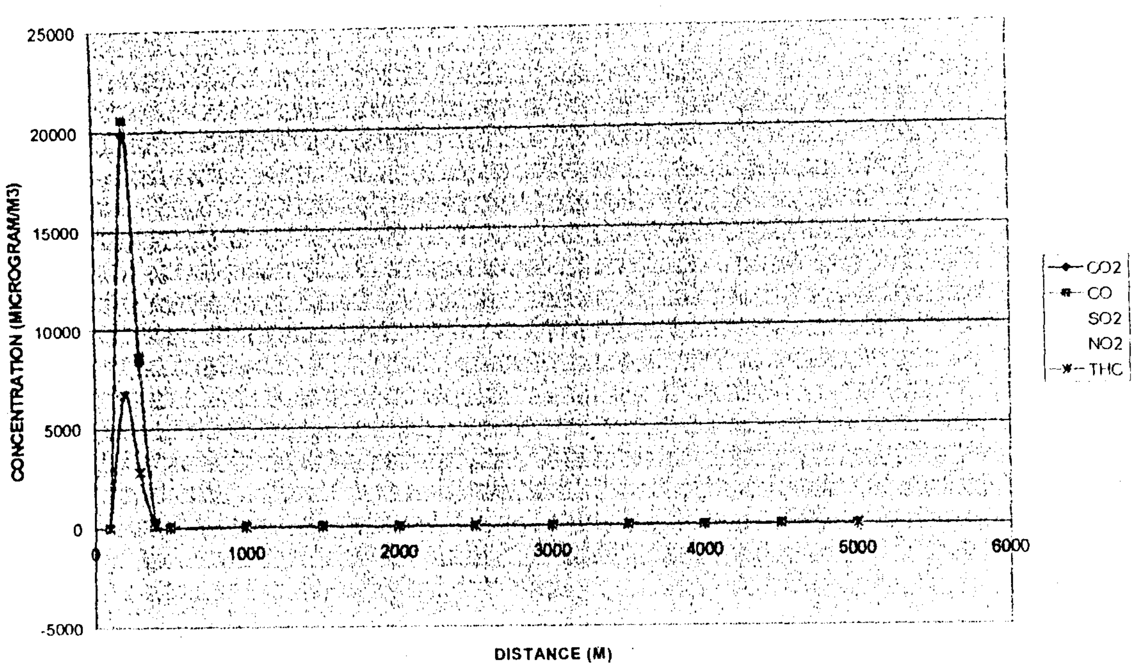
CONCENTRATION VS DISTANCE FOR STATION ONE MONTH OF JAN. (STABLE CONDITION)



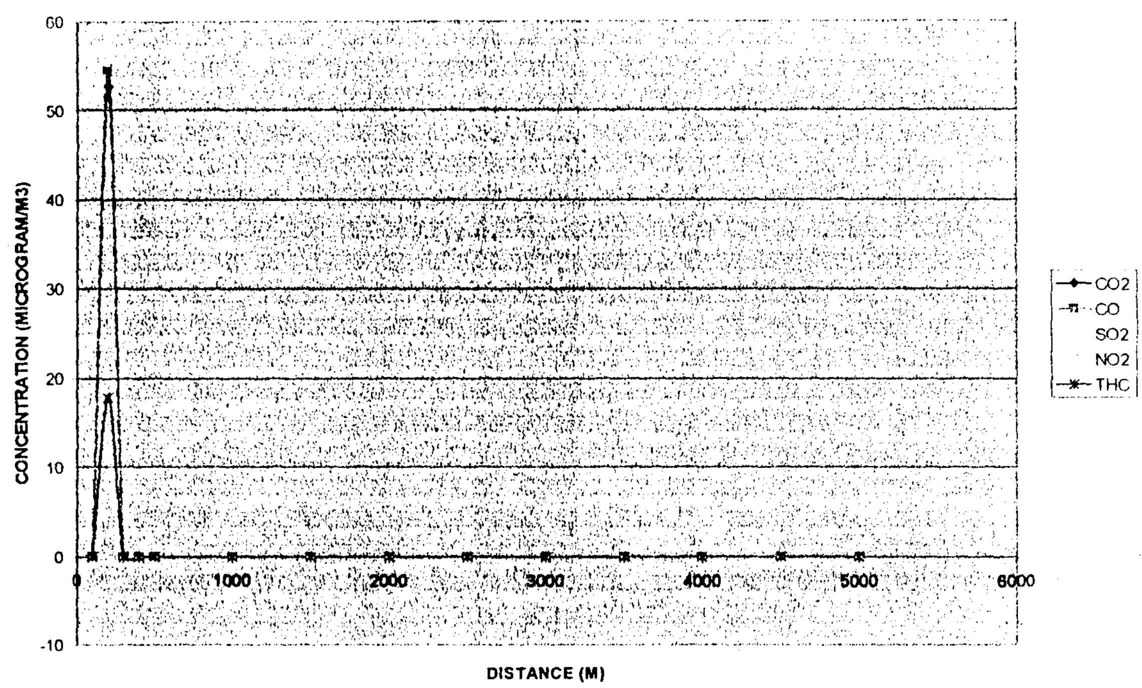
CONCENTRATION VS DISTANCE FOR STATION ONE MONTH OF JAN. (NEUTRAL CONDITION)



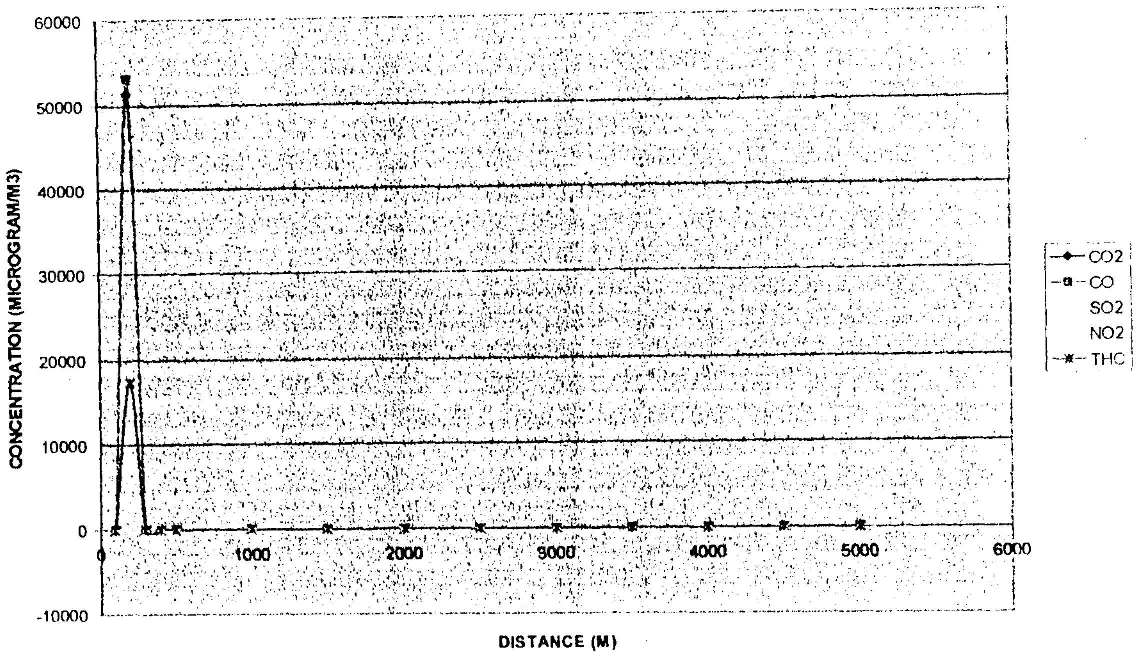
CONCENTRATION VS DISTANCE FOR STATION ONE MONTH OF JAN. (UNSTABLE CONDITION)



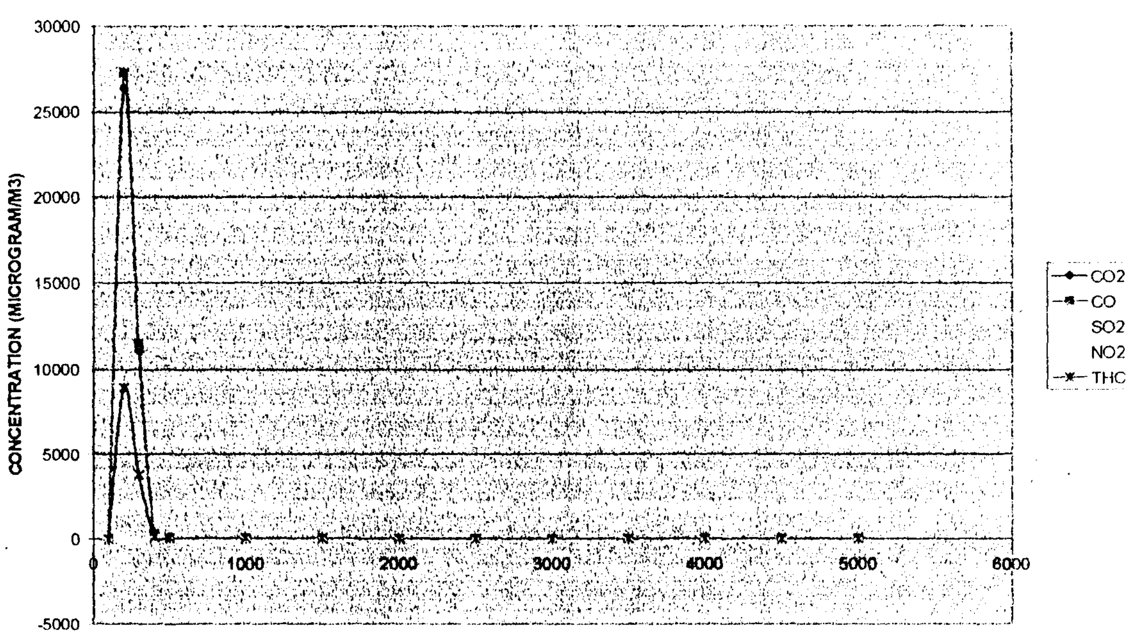
CONCENTRATION VS DISTANCE FOR STATION ONE MONTH OF JUNE.(STABLE CONDITION)



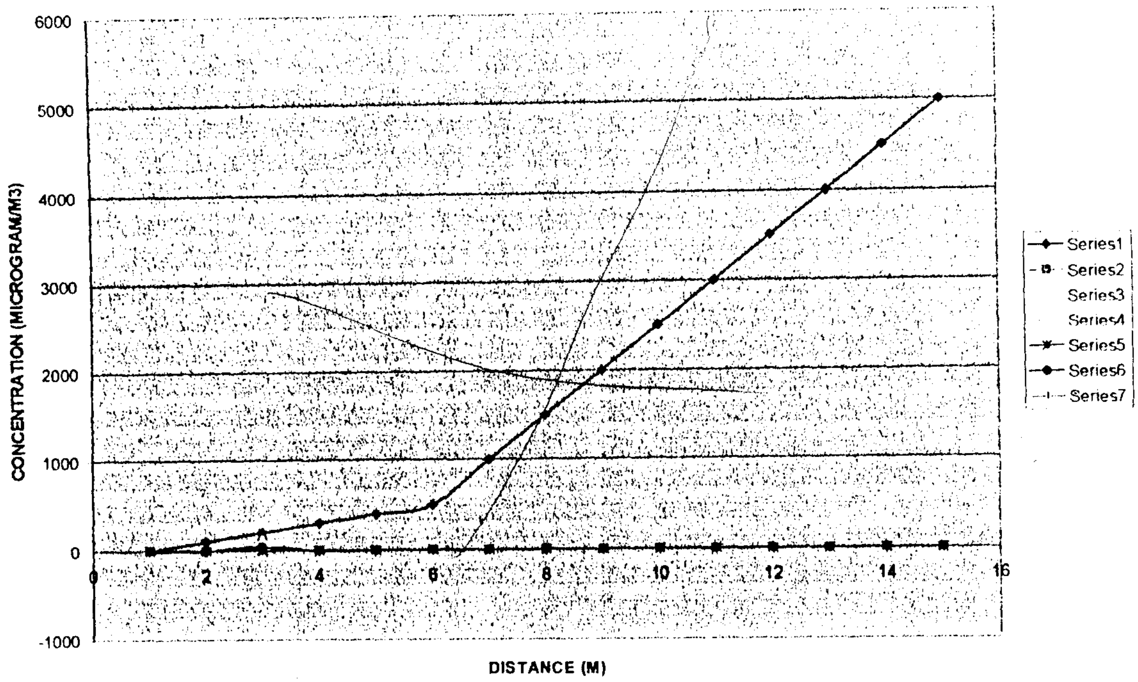
CONCENTRATION VS DISTANCE FOR STATION ONE MONTH OF JUNE. (NEUTRAL CONDITION)



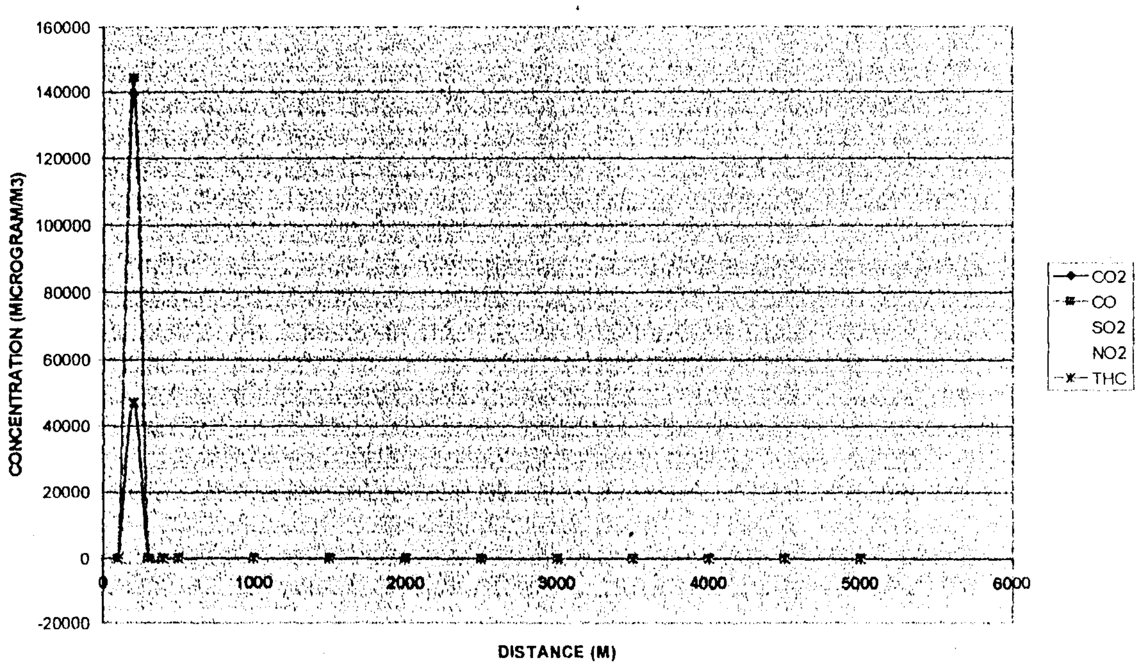
CONCENTRATION VS DISTANCE FOR STATION ONE MONTH OF JUNE. (UNSTABLE CONDITION)



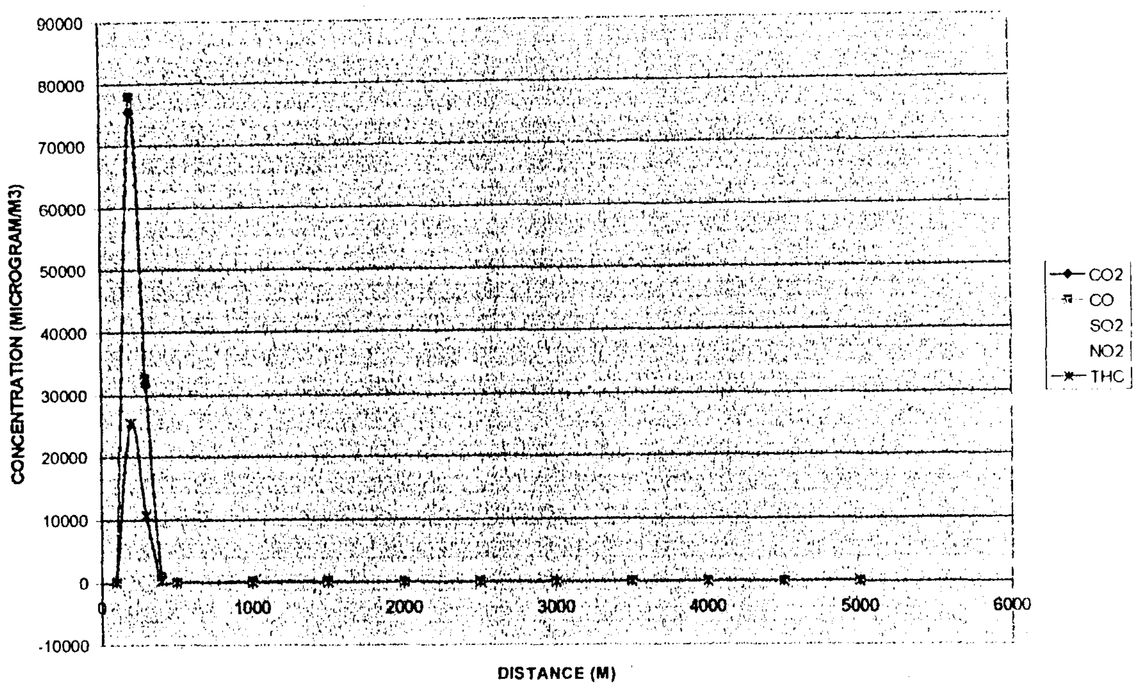
CONCENTRATION VS DISTANCE FOR STATION TWO MONTH OF JAN. (STABLE CONDITION)



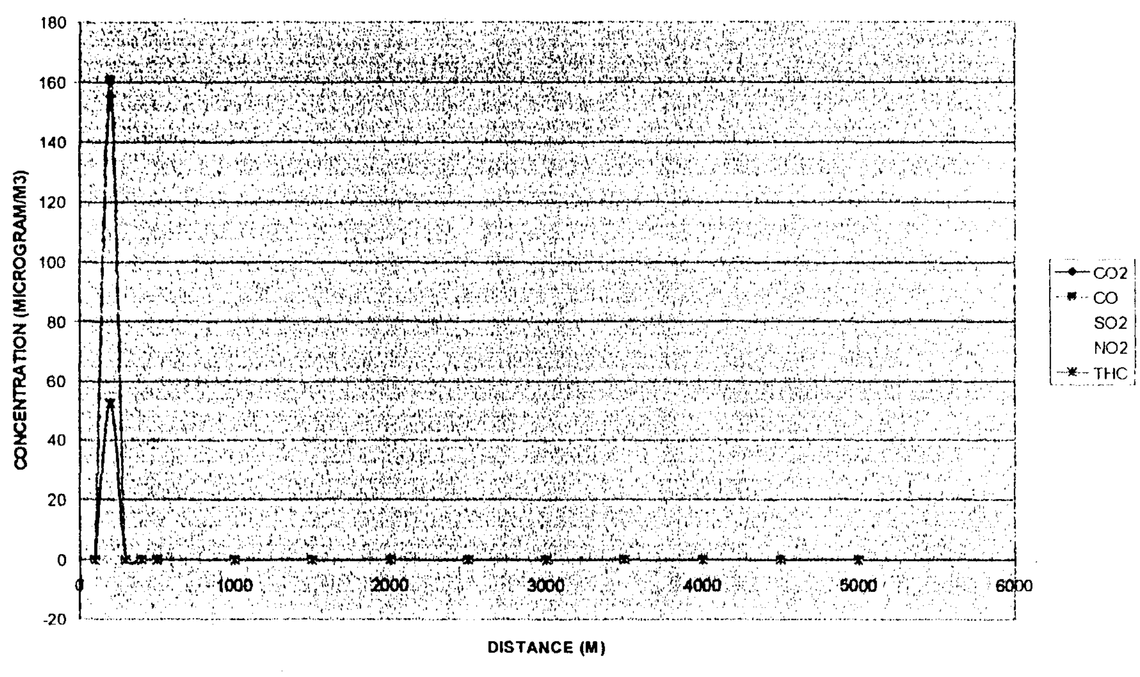
CONCENTRATION VS DISTANCE FOR STATION TWO MONTH OF JAN. (NEUTRAL CONDITION)



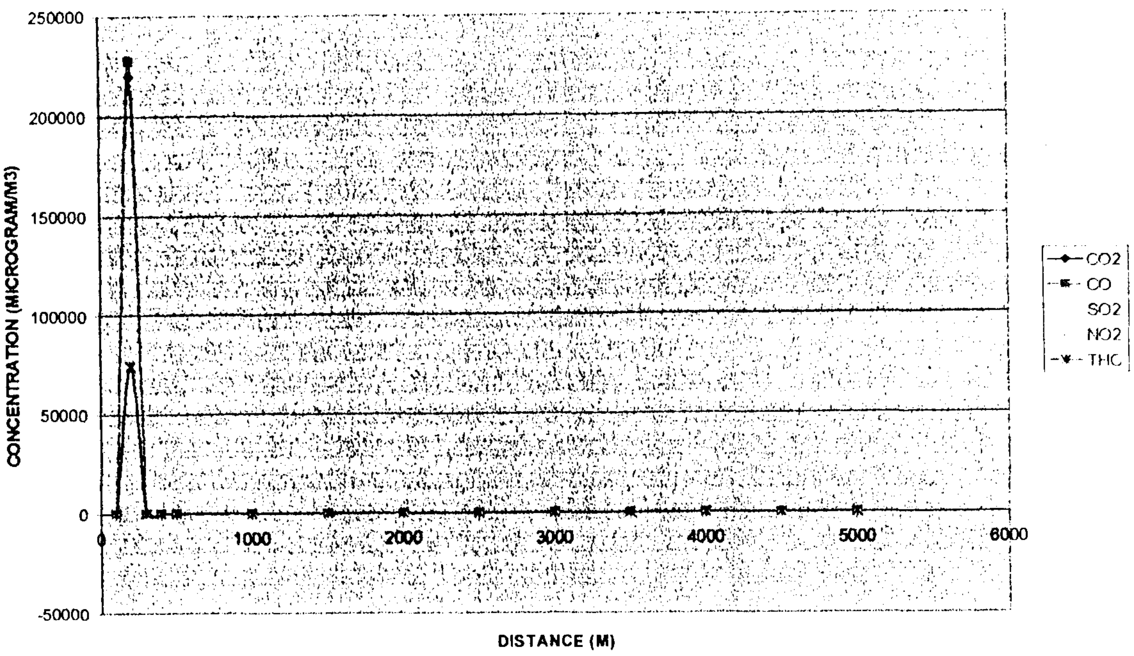
CONCENTRATION VS DISTANCE FOR MONTH OF JAN. (UNSTABLE CONDITION)



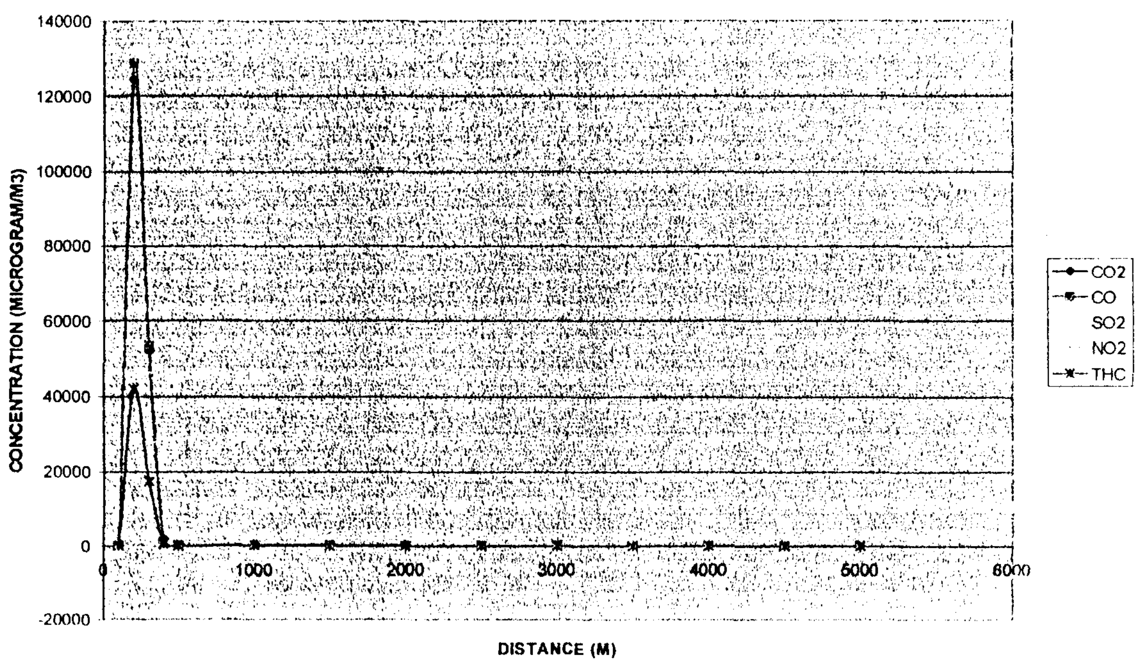
CONCENTRATION VS DISTANCE FOR STATION TWO MONTH OF JUNE. (STABLE CONDITION)



CONCENTRATION VS DISTANCE FOR STATION TWO MONTH OF JUNE. (NEUTRAL CONDITION)



CONCENTRATION VS DISTANCE FOR STATION TWO MONTH OF JUNE. (UNSTABLE CONDITION)



```
Private arrayV_(4), arrayU_(4), arrayTs_(4), arrayTa_(4), arrayVs_(4) As Double
Dim i As Integer
Dim bisi(12) As January
Dim temp As Double
Private V_, Es_, Vs_, Ts_, Ta_, U_ As Double
Private Jy, Jz, Ky, Kz As Double
Private Dco2_, Dco_, Dso2_, Dno2_, Dthc_, Da_, hs_, Cps_, Iy, Iz As Double
Private X, Y, z As Double
Private Sub Form_Load()
    Me.Width = 9795
    Me.Height = 5490
    addComboItems
    setTitle
    textFlds
    loadDensity
    unstable
End Sub
Private Sub stable()
    vol = "Stable"
    dyV(0) = 2.6
    dyV(1) = 0.6564
    dyV(2) = -0.054
    dzV(0) = 3.533
    dzV(1) = 0.9191
    dzV(2) = -0.007
End Sub

Private Sub neutral()
    vol = "Neutral"
    dyV(0) = 3.414
    dyV(1) = 0.7371
    dyV(2) = -0.0316
    dzV(0) = 4.23
    dzV(1) = 0.9222
    dzV(2) = -0.0087
End Sub
Private Sub unstable()
    vol = "Unstable"
    dyV(0) = 6.035
    dyV(1) = 2.1097
    dyV(2) = 0.277
    dzV(0) = 5.357
    dzV(1) = 0.8828
    dzV(2) = -0.0076
End Sub

Private Sub loadDensity()
    For i% = 1 To 4
        Load density(i%)
        density(i%).Visible = True
        density(i%).Top = labTitle2(i%).Top
    Next i%

    density(0) = 1.977
    density(1) = 1.25
    density(2) = 3.125
    density(3) = 1.875
    density(4) = 0.718

End Sub
Private Sub textFlds()
    U(0).Left = station(0).Left + station(0).Width + 400
    Ts(0).Left = U(0).Left + U(0).Width + 200
    Ta(0).Left = Ts(0).Left + Ts(0).Width + 200
    Da(0).Left = Ta(0).Left + Ta(0).Width + 200
    Vs(0).Left = Da(0).Left + Da(0).Width + 200
    hs(0).Left = Vs(0).Left + Vs(0).Width + 200
    Cps(0).Left = hs(0).Left + hs(0).Width + 200
```

```
    U(0).Top = station(0).Top
    Ts(0).Top = station(0).Top
    Ta(0).Top = station(0).Top
    Da(0).Top = station(0).Top
    Vs(0).Top = station(0).Top
    hs(0).Top = station(0).Top
    Cps(0).Top = station(0).Top

    For i% = 1 To 1
        Load Check1(i%)
        Check1(i%).Visible = True
        Check1(i%).Top = station(i%).Top

        Load U(i%)
        U(i%).Left = U(0).Left
        U(i%).Top = station(i%).Top
        U(i%).Visible = True

        Load Ts(i%)
        Ts(i%).Left = Ts(0).Left
        Ts(i%).Top = station(i%).Top
        Ts(i%).Visible = True

        Load Ta(i%)
        Ta(i%).Left = Ta(0).Left
        Ta(i%).Top = Ts(i%).Top
        Ta(i%).Visible = True

        Load Da(i%)
        Da(i%).Left = Da(0).Left
        Da(i%).Top = station(i%).Top
        Da(i%).Visible = True


        Load Vs(i%)
        Vs(i%).Left = Vs(0).Left
        Vs(i%).Top = station(i%).Top
        Vs(i%).Visible = True

        Load hs(i%)
        hs(i%).Left = hs(0).Left
        hs(i%).Top = station(i%).Top
        hs(i%).Visible = True

        Load Cps(i%)
        Cps(i%).Left = Cps(0).Left
        Cps(i%).Top = Ta(i%).Top
        Cps(i%).Visible = True
    Next i%

End Sub

Private Sub setTitle()
    Dim title(22) As String
    Dim ex As Integer
    title(0) = "Input Data"
    title(1) = "U"
    title(2) = "Ts"
    title(3) = "Ta"
    title(4) = "Da"
    title(5) = "Vs"
    title(6) = "hs"
    title(7) = "Cps"
    title(8) = "D_a"

    title(9) = "CO2"
```

```
    title(10) = "CO"
    title(12) = "SO2"
    title(13) = "NO2"
    title(14) = "THC"


    title(15) = "L"
    title(16) = "Cps"
    title(17) = "I_dy"
    title(18) = "I_dz"
    title(19) = "J_dy"
    title(20) = "J_dz"
    title(21) = "K_dy"
    title(22) = "K_dz"

    ex = 1
    Load labTitle(ex)
    labTitle(ex).Caption = title(ex)
    labTitle(ex).Left = labTitle(ex - 1).Left + labTitle(ex - 1).Width + 400
    labTitle(ex).Top = labTitle(ex - 1).Top
    labTitle(ex).Visible = True


    For i% = 2 To 8
        Load labTitle(i%)
        labTitle(i%).Caption = title(i%)
        labTitle(i%).Left = labTitle(i% - 1).Left + labTitle(i% - 1).Width + 200
        labTitle(i%).Top = labTitle(i% - 1).Top
        labTitle(i%).Visible = True
    Next i%

End Sub

Private Sub addComboItems()
    month.AddItem "January"
    month.AddItem "February"
    month.AddItem "March"
    month.AddItem "April"
    month.AddItem "May"
    month.AddItem "June"
    month.AddItem "July"
    month.AddItem "August"
    month.AddItem "September"
    month.AddItem "October"
    month.AddItem "November"
    month.AddItem "December"

End Sub
Private Sub Check1_Click(Index As Integer)
    Dim sta As Integer
    sta = Index
    If (Check1(sta).Value = 1) Then
        U(sta).Enabled = True
        Ts(sta).Enabled = True
        Ta(sta).Enabled = True
        Vs(sta).Enabled = True
        Da(sta).Enabled = True
        hs(sta).Enabled = True
        Cps(sta).Enabled = True
        Es(sta).Enabled = True
    ElseIf (Check1(sta).Value = 0) Then
        U(sta).Enabled = False
        Ts(sta).Enabled = False
        Ta(sta).Enabled = False
        Vs(sta).Enabled = False
        Da(sta).Enabled = False
        hs(sta).Enabled = False
        Cps(sta).Enabled = False
```

```
        Es(sta).Enabled = False
    End If
    'MsgBox "You just clicked Station " & Str$(Index), vbInformation, "Checkbox
Info"

End Sub

Private Sub month_Click()
        Select Case month.Text
        Case "January"
            Jan_Label
        Case "February"
            Feb_Label
        Case "March"
            Mar_Label
        Case "April"
            Apr_Label
        Case "May"
            May_Label
        Case "June"
            Jun_Label
        Case "July"
            Jul_Label
        Case "August"
            Aug_Label
        Case "September"
            Sep_Label
        Case "October"
            Oct_Label
        Case "November"
            Nov_Label
        Case "December"
            Dec_Label
        Case Else
            MsgBox "Invalid Month Selected", 64, "Trouble!"
    End Select


    'MsgBox "Selected Month: " & month.Text & " index: " & Str$(sel(month.Text)),
vbInformation, "Month Info"
End Sub
Private Sub Jan_Label()
    arrayV_(0) = 1.004
    arrayV_(1) = 2.998

    arrayU_(0) = 2.8
    arrayU_(1) = 2.2

    hs_ = 1.2
    Da_ = 1.293
    Cps_ = 2200

    arrayTs_(0) = 900
    arrayTs_(1) = 1000
                  303
    arrayTa_(0) = 304.8
    arrayTa_(1) = 304.5

    For i% = 0 To 1
        U(i%).Text = arrayU_(i%)
        Ts(i%).Text = arrayTs_(i%)
        Ta(i%).Text = arrayTa_(i%)
        Vs(i%).Text = arrayV_(i%)
        Da(i%).Text = Da_
        hs(i%).Text = hs_
        Cps(i%).Text = Cps_
    Next i
End Sub
```

```
Private Sub Feb_Label()
    arrayV_(0) = 0.898
    arrayV_(1) = 3.038

    arrayU_(0) = 2.2
    arrayU_(1) = 2.75

    hs_ = 1.2
    Da_ = 1.293
    Cps_ = 2200

    arrayTs_(0) = 1000
    arrayTs_(1) = 1100

    arrayTa_(0) = 309.5
    arrayTa_(1) = 308.5

    For i% = 0 To 1
        U(i%).Text = arrayU_(i%)
        Ts(i%).Text = arrayTs_(i%)
        Ta(i%).Text = arrayTa_(i%)
        Vs(i%).Text = arrayV_(i%)
        Da(i%).Text = Da_
        hs(i%).Text = hs_
        Cps(i%).Text = Cps_
    Next i
End Sub

Private Sub Mar_Label()
    arrayV_(0) = 0.735
    arrayV_(1) = 3.31

    arrayU_(0) = 2.8
    arrayU_(1) = 1.35

    hs_ = 1.2
    Da_ = 1.293
    Cps_ = 2200

    arrayTs_(0) = 800
    arrayTs_(1) = 900

    arrayTa_(0) = 309.2
    arrayTa_(1) = 309.5

    For i% = 0 To 1
        U(i%).Text = arrayU_(i%)
        Ts(i%).Text = arrayTs_(i%)
        Ta(i%).Text = arrayTa_(i%)
        Vs(i%).Text = arrayV_(i%)
        Da(i%).Text = Da_
        hs(i%).Text = hs_
        Cps(i%).Text = Cps_
    Next i
End Sub

Private Sub Apr_Label()
    arrayV_(0) = 0.706
    arrayV_(1) = 7.024

    arrayU_(0) = 1.39
    arrayU_(1) = 1.28

    hs_ = 1.2
    Da_ = 1.293
    Cps_ = 2200
```

```
    arrayTs_(0) = 750
    arrayTs_(1) = 1100

    arrayTa_(0) = 308
    arrayTa_(1) = 306.5

    For i% = 0 To 1
        U(i%).Text = arrayU_(i%)
        Ts(i%).Text = arrayTs_(i%)
        Ta(i%).Text = arrayTa_(i%)
        Vs(i%).Text = arrayV_(i%)
        Da(i%).Text = Da_
        hs(i%).Text = hs_
        Cps(i%).Text = Cps_
    Next i
End Sub

Private Sub May_Label()
    arrayV_(0) = 0.909
    arrayV_(1) = 5.162

    arrayU_(0) = 2.2
    arrayU_(1) = 1.75

    hs_ = 1.2
    Da_ = 1.293
    Cps_ = 2200

    arrayTs_(0) = 1100
    arrayTs_(1) = 1000

    arrayTa_(0) = 306
    arrayTa_(1) = 310

    For i% = 0 To 1
        U(i%).Text = arrayU_(i%)
        Ts(i%).Text = arrayTs_(i%)
        Ta(i%).Text = arrayTa_(i%)
        Vs(i%).Text = arrayV_(i%)
        Da(i%).Text = Da_
        hs(i%).Text = hs_
        Cps(i%).Text = Cps_
    Next i
End Sub

Private Sub Jun_Label()
    arrayV_(0) = 0.86
    arrayV_(1) = 4.5

    arrayU_(0) = 2.8   → 1.81
    arrayU_(1) = 2.88   → 2.10

    hs_ = 1.2
    Da_ = 1.293
    Cps_ = 2200

    arrayTs_(0) = 880
    arrayTs_(1) = 950

    arrayTa_(0) = 303
    arrayTa_(1) = 306.6

    For i% = 0 To 1
        U(i%).Text = arrayU_(i%)
        Ts(i%).Text = arrayTs_(i%)
        Ta(i%).Text = arrayTa_(i%)
        Vs(i%).Text = arrayV_(i%)
        Da(i%).Text = Da_
```

```
        hs(i%).Text = hs_
        Cps(i%).Text = Cps_
    Next i
d Sub

ivate Sub Jul_Label()
    arrayV_(0) = 0.939
    arrayV_(1) = 4.192

    arrayU_(0) = 1.8
    arrayU_(1) = 1.94

    hs_ = 1.2
    Da_ = 1.293
    Cps_ = 2200

    arrayTs_(0) = 980
    arrayTs_(1) = 900

    arrayTa_(0) = 307.6
    arrayTa_(1) = 304

    For i% = 0 To 1
        U(i%).Text = arrayU_(i%)
        Ts(i%).Text = arrayTs_(i%)
        Ta(i%).Text = arrayTa_(i%)
        Vs(i%).Text = arrayV_(i%)
        Da(i%).Text = Da_
        hs(i%).Text = hs_
        Cps(i%).Text = Cps_
    Next i
End Sub

Private Sub Aug_Label()
    arrayV_(0) = 0.876
    arrayV_(1) = 5.116

    arrayU_(0) = 1.39
    arrayU_(1) = 1.38

    hs_ = 1.2
    Da_ = 1.293
    Cps_ = 2200

    arrayTs_(0) = 900
    arrayTs_(1) = 1050

    arrayTa_(0) = 306.5
    arrayTa_(1) = 303

    For i% = 0 To 1
        U(i%).Text = arrayU_(i%)
        Ts(i%).Text = arrayTs_(i%)
        Ta(i%).Text = arrayTa_(i%)
        Vs(i%).Text = arrayV_(i%)
        Da(i%).Text = Da_
        hs(i%).Text = hs_
        Cps(i%).Text = Cps_
    Next i
End Sub

Private Sub Sep_Label()
    arrayV_(0) = 0.561
    arrayV_(1) = 5.424

    arrayU_(0) = 2.73
    arrayU_(1) = 2#  2.0
```

```
    hs_ = 1.2
    Da_ = 1.293
    Cps_ = 2200

    arrayTs_(0) = 1100
    arrayTs_(1) = 1100

    arrayTa_(0) = 306.3
    arrayTa_(1) = 305.1

    For i% = 0 To 1
        U(i%).Text = arrayU_(i%)
        Ts(i%).Text = arrayTs_(i%)
        Ta(i%).Text = arrayTa_(i%)
        Vs(i%).Text = arrayV_(i%)
        Da(i%).Text = Da_
        hs(i%).Text = hs_
        Cps(i%).Text = Cps_
    Next i
End Sub
Private Sub Oct_Label()
    arrayV_(0) = 0.719
    arrayV_(1) = 4.62

    arrayU_(0) = 2.78
    arrayU_(1) = 1.38

    hs_ = 1.2
    Da_ = 1.293
    Cps_ = 2200

    arrayTs_(0) = 1000
    arrayTs_(1) = 850

    arrayTa_(0) = 307
    arrayTa_(1) = 306

    For i% = 0 To 1
        U(i%).Text = arrayU_(i%)
        Ts(i%).Text = arrayTs_(i%)
        Ta(i%).Text = arrayTa_(i%)
        Vs(i%).Text = arrayV_(i%)
        Da(i%).Text = Da_
        hs(i%).Text = hs_
        Cps(i%).Text = Cps_
    Next i
End Sub

Private Sub Nov_Label()
    arrayV_(0) = 1.067
    arrayV_(1) = 4.781

    arrayU_(0) = 1.38
    arrayU_(1) = 1.39

    hs_ = 1.2
    Da_ = 1.293
    Cps_ = 2200

    arrayTs_(0) = 780
    arrayTs_(1) = 900

    arrayTa_(0) = 305
    arrayTa_(1) = 309

    For i% = 0 To 1
        U(i%).Text = arrayU_(i%)
        Ts(i%).Text = arrayTs_(i%)
```

```
        Ta(i%).Text = arrayTa_(i%)
        Vs(i%).Text = arrayV_(i%)
        Da(i%).Text = Da_
        hs(i%).Text = hs_
        Cps(i%).Text = Cps_
    Next i

End Sub

Private Sub Dec_Label()
    arrayV_(0) = 1.08
    arrayV_(1) = 4.85  -> 4.980

    arrayU_(0) = 1.28
    arrayU_(1) = 2.6

    hs_ = 1.2
    Da_ = 1.293
    Cps_ = 2200

    arrayTs_(0) = 1000
    arrayTs_(1) = 950

    arrayTa_(0) = 308
    arrayTa_(1) = 307.1

    For i% = 0 To 1
        U(i%).Text = arrayU_(i%)
        Ts(i%).Text = arrayTs_(i%)
        Ta(i%).Text = arrayTa_(i%)
        Vs(i%).Text = arrayV_(i%)
        Da(i%).Text = Da_
        hs(i%).Text = hs_
        Cps(i%).Text = Cps_
    Next i
End Sub

Private Sub Option1_Click(Index As Integer)
    Select Case Index
        Case 0
            stable
        Case 1
            neutral
        Case 2
            unstable
    End Select
End Sub

Private Sub reset_Click()
    For i = 0 To 1
        U(i%).Text = ""
        Ts(i%).Text = ""
        Ta(i%).Text = ""
        Vs(i%).Text = ""
        Da(i%).Text = ""
        hs(i%).Text = ""
        Cps(i%).Text = ""
        Es(i%).Text = ""
    Next i
End Sub
Private Function getValues(Index As Integer) As Double
    Dim r As Integer
    Dim ju As Integer
    ju = Index

    V_ = Val(Vs(ju%))
    Vs_ = Val(Vs(ju%))
    Ts_ = Val(Ts(ju%))
```

```
    Ta_ = Val(Ta(ju%))
    U_ = Val(U(ju%))
    Da_ = Val(Da(ju%))
    hs_ = Val(hs(ju%))
    Cps_ = Val(Cps(ju%))

    Iy = Val(dyV(0))
    Iz = Val(dzV(0))
    Jy = Val(dyV(1))
    Jz = Val(dzV(1))
    Ky = Val(dyV(2))
    Kz = Val(dzV(2))

    Dco2_ = Val(density(0))
    Dco_ = Val(density(1))
    Dso2_ = Val(density(2))
    Dno2_ = Val(density(3))
    Dthc_ = Val(density(4))

    Es_ = Val(Es(ju%))
    Efff = Es_


    X = 100
    For r = 1 To 4
        Y = X
        Z = X
        answer(r, 0) = Conc_co2
        answer(r, 1) = Conc_co
        answer(r, 2) = Conc_so2
        answer(r, 3) = Conc_no2
        answer(r, 4) = Conc_thc
        X = X + 100
    Next r
    X = 500
    For r = 5 To 13
        Y = X
        Z = X
        answer(r, 0) = Conc_co2
        answer(r, 1) = Conc_co
        answer(r, 2) = Conc_so2
        answer(r, 3) = Conc_no2
        answer(r, 4) = Conc_thc
        X = X + 500
    Next r
    getValues = 0
End Function

Private Sub simulate_Click()
    On Error GoTo mineError

retry:
    Dim select_, chec As Integer
    select_ = sel(month.Text)
    If select_ = 0 Then
        'Do Nothing
    Else
        Dim j As Integer
        For j = 0 To 1
            chec = j
            getValues (j)
            temp = Vs_
            MsgBox "Sim Complete: Volume = " & temp
            whatsta = Str$(chec + 1)
            Set bisi(select_) = New January
            Load bisi(select_)
            bisi(select_).Show
        Next j
```

```
    End If
    Exit Sub
heError:
    Dim response As Integer, Description As Integer
    Description = vbExclamation + vbRetryCancel
    response = MsgBox(Err.Description & ": Invalid Data!!!", Description,
nvalid Data Error")
    If response = vbRetry Then
        Resume retry
    End If
d Sub
ivate Function sel(mon As String) As Integer
    'ReDim bisi(12) As January
    selMonth = mon
    Select Case mon
        Case "January"
            sel = 1
        Case "February"
            sel = 2
        Case "March"
            sel = 3
        Case "April"
            sel = 4
        Case "May"
            sel = 5
        Case "June"
            sel = 6
        Case "July"
            sel = 7
        Case "August"
            sel = 8
        Case "September"
            sel = 9
        Case "October"
            sel = 10
        Case "November"
            sel = 11
        Case "December"
            sel = 12
        Case Else
            sel = 0
            MsgBox "Invalid Month Selected", vbExclamation, "Trouble!"
    End Select
End Function

Private Function Qc() As Double
    Qc = Cps_ * (Da_ * Ta_ / Ts_) * Vs_ * (Ts_ - Ta_)
End Function

Private Function delta_h() As Double
    delta_h = 1.6 * ((7.56 * 10 ^ -7 * Qc()) ^ (1 / 3)) * ((10 * hs_) ^ (2 / 3))
* (U_ ^ (-1))
End Function

Private Function hfv() As Double
    hfv = 0.0042 * (Cps_ * Da_ * Ta_ / Ts_ * Vs_ * (Ts_ - Ta_)) ^ 0.478
End Function

Private Function H() As Double
    H = hs_ + hfv() + delta_h()
End Function

Private Function L_() As Double
    L_ = 2 * H()
End Function

Private Function dy() As Double
    dy = Exp(Iy + Jy * Sin(X) + Ky * (Sin(X)) ^ 2)
```

```
nd Function

rivate Function dz() As Double
    dz = Exp(Iz + Jz * Sin(X) + Kz * (Sin(X)) ^ 2)
nd Function

rivate Function Conc_co2() As Double
    Conc_co2 = (7.55 * (10 ^ -3) * Es_ * Dco2_ * V_) / (2 * 3.142 * U_ * dy() *
lz()) * Exp(-(Y ^ 2) / (2 * dy() ^ 2) - (H() ^ 2) / (2 * dz() ^ 2))
End Function

Private Function Conc_co() As Double
    Conc_co = (0.01235 * Es_ * Dco_ * V_) / (2 * 3.142 * dy() * dz() * U_) *
Exp(-(Y ^ 2) / (2 * dy() ^ 2) - (H() ^ 2) / (2 * dz() ^ 2))
End Function

Private Function Conc_so2() As Double
    Conc_so2 = (3.06 * (10 ^ -6) * Es_ * Dso2_ * V_) / (2 * 3.142 * dy() * dz() *
U_) * Exp(-(Y ^ 2) / (2 * dy() ^ 2) - (H() ^ 2) / (2 * dz() ^ 2))
End Function

Private Function Conc_no2() As Double
    Conc_no2 = (4.4 * (10 ^ -6) * Es_ * Dno2_ * V_) / (2 * 3.142 * dy() * dz() *
U_) * Exp(-(Y ^ 2) / (2 * dy() ^ 2) - (H() ^ 2) / (2 * dz() ^ 2))
End Function

Private Function Conc_thc() As Double
    Conc_thc = ((0.99 - 0.00845 * Es_) * Dthc_ * V_) / (2 * 3.142 * dy() * dz() *
U_) * Exp(-(Y ^ 2) / (2 * dy() ^ 2) - (H() ^ 2) / (2 * dz() ^ 2))
End Function


Public fMainForm As frmMain
Public bisi() As January
'Dim chec As Integer
Public selMonth, whatsta, vol As String
Public answer(14, 5) As Double
Public Efff As Double


Sub Main()
    frmSplash.Show
    frmSplash.Refresh
    Set fMainForm = New frmMain
    Load fMainForm
    Unload frmSplash
    fMainForm.Show
End Sub
```