MODELING AND SIMULATION OF THE EFFECT OF GAS FLARING ON SOIL TEMPERATURE.A CASE STUDY OF NIGER-DELTA.

BY

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DECLARATION

I ADELELKE ADEIGA .A. B.ENG/CHEM/98/6815,hereby declare that this thesis: EFFECT OF GAS FLARING ON SOIL TEMPERATURE BY COMPUTER SIMULATION, presented for the award of bachelor in chemical engineering, has not been presented for any other degree else

22/11/2004

SIGNATURE DATE

CERTIFICATION

This is to certify that this project was supervised, moderated and approved by the following under listed persons on behalf of the chemical engineering department, school of engineering and engineering technology, federal university of technology Minna.

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(HEAD OF DEPARTMENT)

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EXTERNAL SUPERVISOR DATE

DEDICATION

This work is dedicated to Almighty God for his guidance and protection over me through out my really tough times in my academic pursuit, to my parents and families who supported me both morally and financially and to my friends Ola Aboloye, Oga Ajima and Tosin Bashua-Alimi.

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ABSTRACT

Nigeria has an extensive natural gas resources and the lack of non-provision of proper gas routes of utilizing this natural resources has led to wastage of the gas through gas flaring. Nigeria flares an enormous 'quantity of gas per day' and this has a detrimental effect on the environment. One obvious effect is the increase in the soil temperature of the region close to the flare points. The objective of this project is the modeling of the effect soil temperature as a result of gas flaring, using visual Basic program. The simulation result conforms to the experimental results of the soil temperature measured at various distances. From the result, it is clearly shown that the soil temperature decreases with increase in distance from the flare point and also the soil temperature depends largely on the volume of gas being flare and the absorptivity of the soil in the area.

CHAPTER I

1.0 INTRODUCTION

Nigeria has a population of over 110million people and an abundance of natural resources especially hydrocarbons. Oil was discovered in Nigeria in 1956 at Oloibiri in the Niger-Delta after half a century of exploration (Mbendi, 2000). The discovery was made by Shell-BP, at the time the company is the sole concessionaire. Nigeria joined the ranks of oil producers in 1958 when its first oil field came on stream producing 5,100bpd (Thisday online, 2000). Nigeria joined the Organisation of Petroleum Exporting Countries (OPEC) in 1971 and established the Nigeria National Petroleum Company (NNPC) in 1977; a state owned and controlled company which is a major player in both the upstream and downstream sector (Mbendi, 2000). Nigeria contains estimated proven oil reserves of 22.5billion barrels and produces 90million tones per year (2million bpd) of crude oil (Obadina, 2000). Today, Nigeria is the 10th largest oil producer in the world (coming behind Algeria, Indonesia, Iran, Kuwait, Saudi Arabia, the United Arab Emirates, Venezuela), the third largest in Africa (Mbendi, 2000). The Nigerian economy is largely dependent on its oil sector which supplies 95% of its foreign earnings (Tunde, 2000). Nigeria's oil reserves contain gas, a natural by-product when oil is drilled, which is separated from the oil at flow stations. An estimate of Nigeria's proven natural gas reserves are approximately 124 trillion cubic feet (Bakare, 1999). The discovery of crude oil has enhanced the engine of the economic development by supplying the needed energy and raw material. It has therefore enhanced our way of life via industrialization and improving technology in Nigeria. However, while the exploitation and exploration of oil has created some fortunes and contributed positively to the economic and technological advancement of Nigeria as a country, the accompanying socio-economic and ecological fallouts remain grievous. The public considers the oil producing companies operating in the Niger-Delta oil fields responsible for polluting the environment by way of relentless flaring and venting of gas in the environment, oil spillages, site clearing, deforestation and destruction of flora and fauna, and disturbances of the ecosystem in the 70,000 square kilometres Niger-Delta wetland (Oguejifor, 1993). Gas flaring in Nigeria today has posses an environmental hazard to the nation at large. So much damage is being done to the environment through gas flaring, that if nothing is done in a few years from now, serious environmental and health problems such as premature death and diseases will emerge. With respect to gas flaring, its effect on vegetation, health and the micro-climate are equal searing. Apart from the noise produced from the fire at the flare sites, the thick smoke that bellows into the sky contains poisonous gases which give rise to acid rain and eventually poison streams, lakes, lagoons and rivers thereby destroying aquatic organism and making the water unhealthy for drinking. It has been proven that gas flaring generates heat which is felt over an average radius of 0.5 kilometres thereby causing thermal pollution (Ikelegbe, 1993).

1.1 JUSTIFICATION OF PROJECT

Nigeria being rich with abundance of crude oil has led to environmental concern in terms of safety and people's health that result during the cause of exploration and exploitation of the crude oil. The exploration and exploitation of crude oil has actually made Nigeria a mono economy in the sense that a lot of pressure has been applied in exploring the crude oil but unfortunately little or no effort has been done in the control of adverse effect of the flared gases. As a result of this, people have been urged to tackle this problem so as to make the environment friendly to humans as well as the ecosystem and this has prompted various researches particularly in the Niger-Delta area. The shell petroleum development Company, 1999 wrote on flared gas management where they explained why gas is flared and gave on overview of their commitment on flared gas management options. However, Oyekunle (1999) worked on gas flaring in Nigeria and environmental pollution control and also, Ekunadayo (1999) worked on the safety and environmental concerns in natural gas utilization and some group determined the quantities of the various parameters released into the air during gas flaring at various distance from the flare sites. It could be observed that however though much work has been done on gas flaring, but little has been done so far on modelling and simulation of the effect of gas flaring on soil temperature. This project is geared towards the development of a model that will be used to show the effect of gas flaring on soil temperature at various distances.

1.2 SCOPE OF STUDY

The project is to investigate the effect of gas flaring on soil temperature using Niger-Delta as a case study and taking the soil temperature condition in various areas at various distances around the flare site.

1.3 AIMS AND OBJECTIVES

This project focuses on the effect of gas flaring on soil temperature during the exploration of oil in the Niger-Delta area by computer simulation. This project is therefore aimed at:

1. Developing a predictive model for soil temperature.
2. Collected data/experimental analysis on the soil in the gas flare station to determine the validity of this model result.
3. Finding interaction between various parameters that affects soil temperature from gas flaring like the volume of gas flared temperature of flared stack, surrounding temperature, stack efficiency etc.
4. Simulating the derived mathematical model using visual basic.

CHAPTER 2

2.0 LITERATURE REVIEW

Everyday in southern Nigeria, almost 2million cubic feet of natural gas is burnt (flared) during crude oil production, more than is flared anywhere else in the world (Obadina, 2000). In fact, Nigeria ranks the tenth largest proven natural gas reserves and gas flared in Nigeria is equivalent to the total annual power generation in the sub-Saharan Africa 'according to World Bank'. Gas flaring not only wastes valuable resources, but is also a major cause of environment pollution in the Niger-Delta, where most of Nigeria's oil output is produced. There is growing anger among local inhabitants at the damages caused to their health and ecosystem by oil production activities, especially gas flaring and crude oil spillage. It has also been noted that there are currently 100 gas flaring sites, some of which have been burning ceaselessly for 40 years (Darah, 1998). Each one of these bonfires has an adverse effect on the inhabitants and the natural environment. The extent of human damage attributable to gas flaring is unclear, but doctors have found an unusual high incidence of asthma, bronchitis, skin and breathing problems in communities in oil producing areas. Moreover, flaring is a global source of green house gas emissions, contributing to global warming. The World Bank estimates that gas flaring in the Niger-Delta releases some 35 million tonnes of Carbon dioxide annually into the air (Obadina, 2000). More natural gas is flared in Nigeria's oil field more than anywhere else in the world (National gas policy, 1999). The gas that is being flared is very heavy in carbon. The flames rage non-stop, day and night. When it rains, the carbon pollutes the streams and farms, in addition to damaging the corrugated roofs of people's houses. In communities where this occurs, people have to change the roofs on their houses every four to five years. However, unlike in many other parts of the world, Nigeria's gas is wasted through flaring with little care. Flared gas releases hazardous substances into the environment that heighten the problem of the depletion of the Ozone layer. The attendant "green house effect" is one of the most frightening environment problems of our time. Ozone layers that serve as blanket for regulating the earth's temperature are stripped as a resulting of gas flaring thereby causing global warming. In spite of advances in technology and the potential to convert the flared gas into a source of enormous nation revenue, the practices has continued in Nigeria, ostensibly underscoring the problems of our national development. Gas flaring leads to generation of heat which causes an increase in heat waves hence there will be more people who will suffer heart stroke, heart attacks and other ailments aggravated by the heat. A heat wave killed more than 700 people in Chicago area alone and if this is happening already from heat, what would occur in the future with global warming. And this heat also, causes an increase in the soil temperature which with subsequent increment in temperature destroys the plant thereby affecting the ecosystem since plants absorb co_2 in the atmosphere. The world health organisation advised the Nigerian government to address this problem by paying close attention to the activities of companies engaged in gas flaring and the environmental problems associated with their exploratory methods and to invites experts from developed countries to work with Nigerian professionals and environmentalists to work out a remedy (Gas flaring should stop, 2000). Critics of the flares in the Niger-Delta have said that the Nigerian government puts profit ahead of the environmental safety and the welfare of its citizens. This position is buttressed by (Isaac Osuoko, 2000), who says that oil and gas companies have blackmailed the Nigerian government to cancel or weaken regulation on gas flaring, preferring the cheap option of paying parity fines for the over 600 billion cubic feet of associated gas flared yearly from the oil and gas fields of the Niger-Delta area into the atmosphere (Niger-Delta communities protest neglect, 2000). Though flaring of gas may be a cheap option for oil and gas companies, the cost borne by the local people and the environments cannot be measured in monetary terms. Apart from acid rain, noise and soot pollution and the health risks to the people on the oil and gas fields, the entire planet is affected, as gas flaring from the area accounts for a significant amount of the carbon dioxide and methane emissions which contributes greatly to global warming. The villages complain that the heat and the noise from the flare have scared away wild game and chased fish from the streams. Villagers say the soil is affected, also affected is the small yield of crops such as cassava and potatoes yearly. According to the former Head of National Petroleum Corporation (Tsatsu Tsikata, 2001), "Natural gas estimated between 3 to 4 billion cubic feet a day is being flared in the oil fields of Nigeria, contributing to the instability of rainfall pattern in the sub-region due to pollution. Furthermore, about 20,000 mega watts of power more than the existing installed capacity in West Africa can be generated from Nigeria's flared gas. This he says is enough to light up every village in West Africa (Tsatsy Tsikata, 2001). The late Ken Saro Wiwa, author and spokesperson for the Movement for the Survival of Ogoni people (MOSOP), argued that apart from physical destruction to plants around the flaring areas, thick soot are deposited on building roofs of neighbouring villages whenever it rains, the soot are washed off and the black ink like water running down the roofs is believed to contain chemical substances which adversely affect the fertility of the soil (Ken Saro Wiwa, 1993). Although atmosphere is a self cleaning entity, but when the rate of generation of these contaminants exceeds the rate of removal, accumulation occurs thereby causing environmental hazard. Such major contaminants are the green house gas like CO_2, CO, SO_2, N_2O, and CFC etc. Carbon dioxide in the atmosphere is known by scientist to be on the increase and is far more than what is needed by green vegetation. Also the excess of carbon dioxide that is released into the reflected from the earth surface and consequently cause increase in atmospheric temperature. Scientists have discovered that over years the average surface temperature of the earth increased between 0.3 and 0.6 degrees Celsius (Akinfesoye, 1999). Apart from increasing the level of soil temperature which is unbearable to most plants, it could also cause skin problems to human and animals. Due to the serious problem caused by pollutants on the environment, scientists and engineers have now been concentrating generally on environment management as a tool of liberation in improving the quality of life and to make the environment friendly for human beings. This however brings about models and simulation, which is now applied generally to look into the inter-relationship between the parameters and its resultant effect on the environments.

2.1 Natural Gas

Natural gas is so called because it occurs naturally. It is formed from sediments rich in organic matter which in the past have been exposed to very high temperatures and pressures and found in underground structures similar to those containing crude oil and may or may not be associated directly with corresponding accumulation of oil. Natural gas is classified as either associated gas i.e. produced in association with crude oil and separated at flow station or as non-associated gas i.e. produced directly from gas well.

2.1.1 Chemical Composition of Natural Gas

Natural gas is a naturally occurring gas mixture consisting mainly of methane. The composition of natural gas varies according to its origin, type, genesis and location of the deposit, geological structure of the region as well as other factors. Natural gas is approximately 80 – 90 % methane, with the remainder being mostly other hydrocarbons (ethane, propane, butane etc) as well as some Nitrogen, Oxygen, Water, Carbon dioxide, Sulphur and various contaminants. The table below outlines the typical components of Nigeria's natural gas.

Table 2.1A: Typical components of Nigeria's Natural Gas.

Component	Natural Analysis A	Gas (Mole %) B	Reservoir Agip C	Well Oil D	Stream Company E	Sample F
Nitrogen	0.24	Nil	0.82	1.83	Nil	Nil
Carbon dioxide	2.26	0.30	0.73	0.70	0.41	Nil
Hydro sulphide	Nil	Nil	Nil	Nil	Nil	Nil
Methane	88.76	96.65	90.86	90.06	92.76	80.36
Ethane	4.76	2.05	4.03	4.05	3.03	11.86
Propane	2.67	0.47	1.30	1.51	1.36	5.19
Butanes (n & i)	0.63	0.17	0.77	1.11	0.80	1.66
Pentanes (n & i)	0.38	0.05	0.39	0.45	0.39	0.54
Hexane	0.30	0.31	1.10	0.18	0.26	0.37
Heptanes and Heavier	Nil	Trace	Not recorded	0.11	0.99	Nil

Gas flaring is simply burning up of associated gas (natural gas that is released with crude oil production) i.e. disposing waste gases through combustion. The various chemicals released during flaring operations are listed below.

2.2.1 Hydrogen Sulphide, H_2S

Hydrogen Sulphide is contained in Natural gas and it is discovered more in sour gas. A fraction of Hydrogen sulphide is released during gas flaring operations. Sour gas is defined by Canadian work safety standards as natural gas which contains more than 10ppm of hydrogen sulphide (0.001%). The petroleum industry defines it as natural gas that contains more 1% hydrogen sulphide. Hydrogen sulphide is a colourless gas with a strong smell of rotten eggs and is highly flammable. It is highly intoxicating. It causes skin and eye problem when they come in contact. A single breath of gas containing 0.01% of hydrogen sulphide may cause coma .(WWW.oxford/tech/hsci.com)

2.2.2 Sulphur dioxide, SO_2

Sulphur dioxide is a major component of a group of airborne contaminants termed "acidifying emission". Sulphur dioxide is emitted from various sources including sour gas production, flaring at oil facilities, well test flares, gas plants and oil sand facilities. These emissions can combine with water in the atmosphere to form acids. It is a colourless liquid or pungent gas about 2.5 times as heavy as air, with a suffocating smell, faint sweetish colour.

2.2.3 CS_2 and COS

Combustion of H_2S can produce small quantities of other sulphur compounds such as carbon disulphide (CS_2) and Carbonyl sulphide (COS). CS_2 is highly odorous and toxic when absorbed through the skin. COS is considerably less toxic, although high concentrations have a narcotic effect.

2.2.4 Oxides of Nitrogen, NOx

Nitrogen oxides are mixture of gases that are composed of Nitrogen and Oxygen as a result of combustion. Two of the most toxicologically significant of Nitrogen oxides are nitric oxide and nitrogen dioxide. Both are non-flammable and colourless to brown at room temperature. Nitric Oxide is a sharp sweet smelling gas at room temperature, whereas, nitrogen dioxide has a strong, harsh odour and is a liquid at room temperature, becoming a reddish brown gas above 70^0F. Low levels of nitrogen oxides in the air can irritate our eyes, nose, throat and lungs and possibly cause cough or shortness of breath, tiredness and nausea.

2.2.5 VOCS

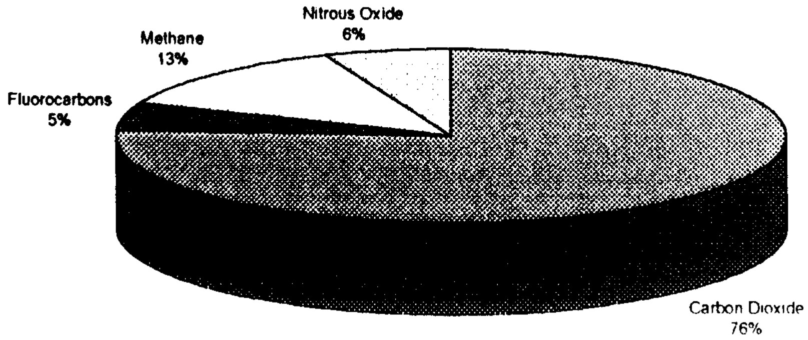
Under some circumstances, inefficient combustion of hydrocarbons may also produce volatile organic compounds (VOCs) such as benzene, toluene and xylene. These three compounds are all classified as toxic, and benzene is a known cancer causing compound with nitrogen oxides in the presence of sunlight, VOCs contribute to ground level Ozone and smog.

The release of these gases has adverse effects on the environment, which has been of concern to Nigeria and world at large. Three major effects of the presence of theses gases in the atmosphere are discussed below.

2.3 Green House Gases

Naturally occurring green house gases maintain the earth's surface at a temperature 33^0C warmer than it would be in their absence (WWW.JulianPrime@dfi.gsi.gov.uk). Water vapour is by far the most important green house gas but there also has a significant nature as sources of Carbon dioxide, Nitrous oxide, methane and fluorocarbons. At present the green house gas concentration in the atmosphere are increasing as a result of human activities such as gas flaring, industrial combustion etc. There is new and stronger evidence the most of the warming observed over the last 50 years is attributable to human activities. Figure 2.1 shows the distribution of green house gases in order of their estimated contribution to global warming. And some these gases are discussed below:

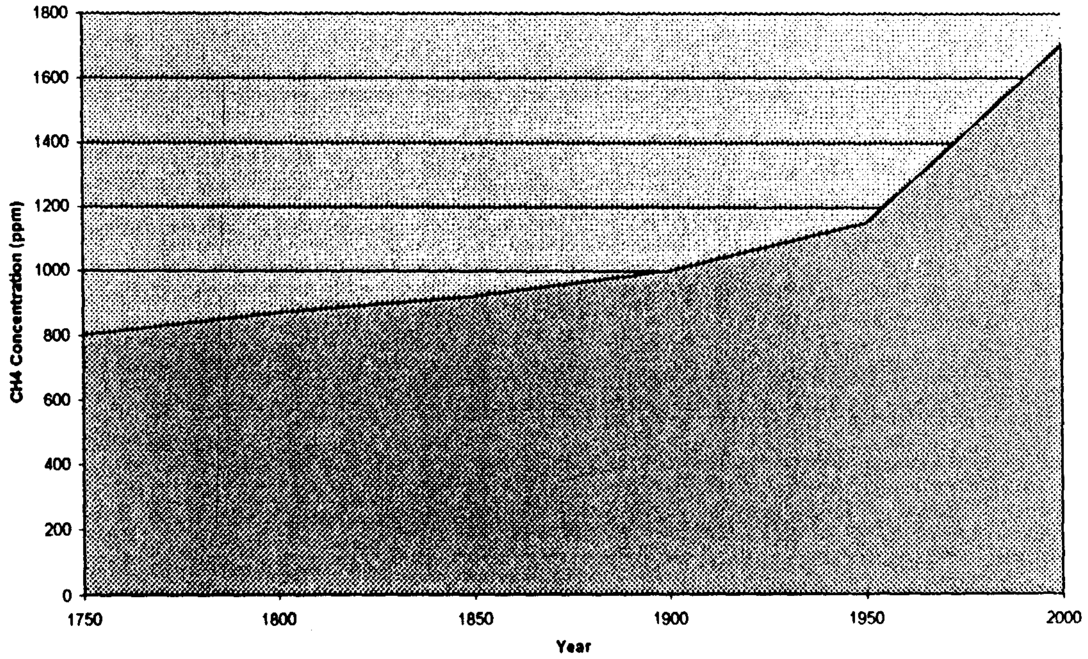
FIGURE 2.1:Distribution of Greenhouse Gases in the Earth's Atmosphere



2.3.1 Carbon dioxide (CO_2)

Carbon dioxide (CO_2) is a colourless, odourless, non-flammable gas and is the most prominent greenhouse gas in earth's atmosphere (www.abcnews.com). It is recycled through the atmosphere by the process of photosynthesis, which makes human race possible to this very day. CO_2 is by far the greatest contributor to climatic change, accounting about 64% of estimated current global warming (www.eccs/umich.edu/mathscience/funexperiments/agesubject.html). Once emitted a specific amount of carbon dioxide cycles through the atmosphere before being permanently removed by oceanic processes or at long term increases in terrestrial biotic storage (i.e., uptake by plants). When the rate of emission of a green house gas is greater than the rate of removal, then its atmospheric concentration increases. The amount of time in which about 63% of the emissions of gases are removed from the atmosphere is called its effective residence time (www.abcnews.com). There is often a considerably uncertainty in this crucial parameter, which is important for calculating the climate effects of a green house gas. The range of effective residence time of carbon dioxide is 50 to 200 years. And figure 2.2 shows the increase of CO_2 in the atmosphere from 1750 to 2000.

FIGURE 2.3:Methane Rise since 1750



2.3.3 Halocarbons

Halocarbons are class of chemical compounds which have one or more atoms belonging to the halogen group of elements such as fluorine and chlorine. The most abundant halocarbons in terms of their contribution to global warming are chlorofluorocarbons (CFCs, also known by the trade as Freon.); specifically CFC-11 and CFC-12. Though existing in relatively trace amounts in the atmosphere, these chemical compounds exhibit powerful radiative trapping ability in addition to their well-known Ozone depleting properties. Halocarbons account for about 10% of current global warming, but the atmospheric concentration of these compounds has begun to fall as a result of an international ban on their production and consumption. Measurements of similar chemicals used as substitutes for CFCs, hydro chlorofluorocarbons (HCFCs) and hydro-fluorocarbons (HFCs) are now showing concentration increase. Should

Table 2.1b: The Principal Greenhouse Distribution

Gas		CO_2	CH_4	CFC – 11	CFC – 12	N_2O
Concentration Present (Pre-industrial)		280ppmv	0.79ppmv	0	0	280ppbv
		353ppmv	1.72ppmv	280pptv	484pptv	310ppbv
Lifetime in atmosphere (years)		50 - 200	10	65	130	150
Global warming potential relative to CO2**	20 yrs	1	63	4500	7100	270
	100yrs	1	21	3500	7300	290
	500yrs	1	9	1500	4500	190
Contribution to total radiative effect as at 1980-1990(%)		55	15	24(all CFC's)	All CFC's	6

Reference

- Data from exploration and production working group 1 Shell BP
- The warming effect of an emission of 1kg of each gas relative to CO_2 based on the present day atmosphere where

  1ppmv – 1 part per million (10^6) on a volume basis

  1ppbv – 1 part per billion (10^9) on a volume basis

  1pptv – 1 part per trillion (10^{12}) on a volume basis

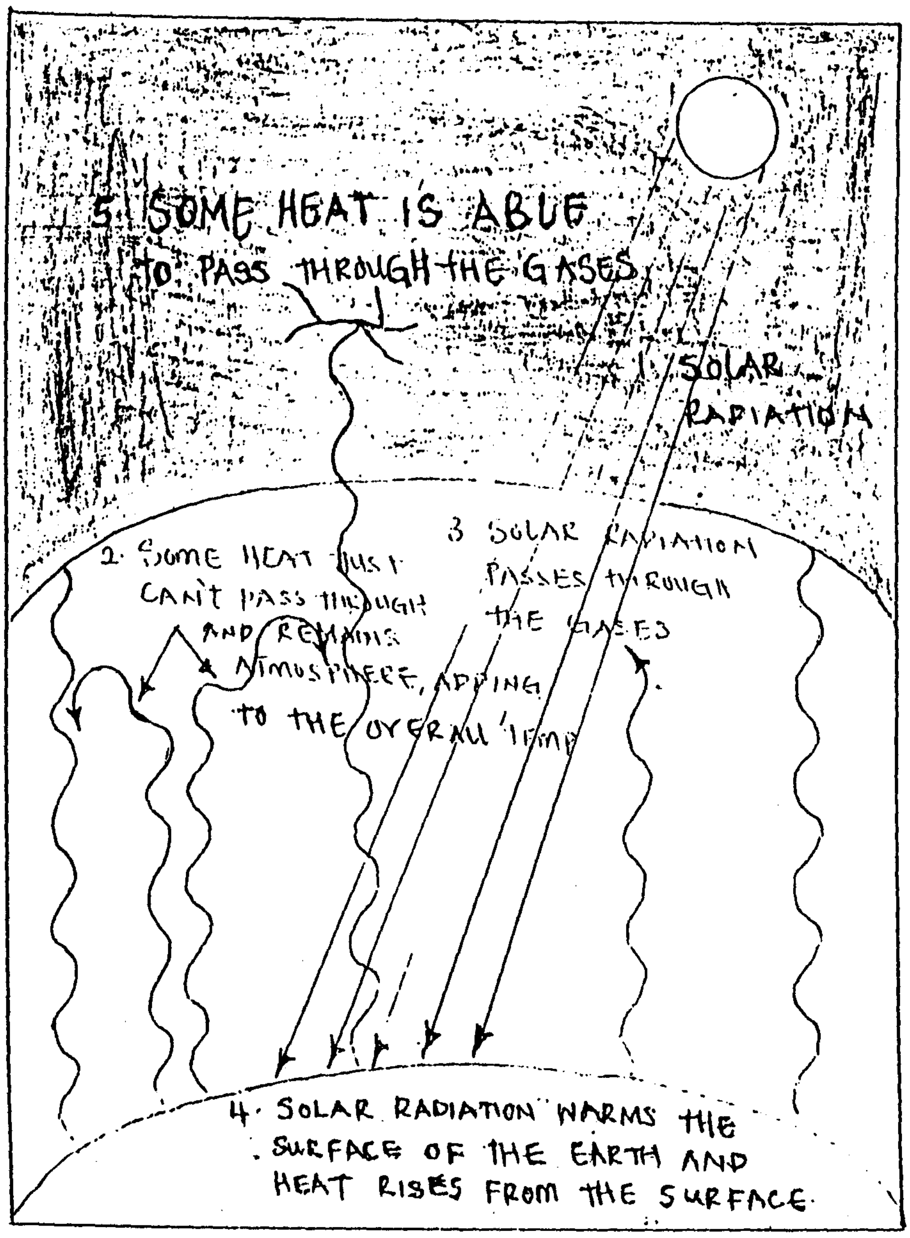


FIGURE 2.6: DIAGRAM TO HELP EXPLAIN THE PROCESS OF GLOBAL WARMING AND HOW GREENHOUSE GASES CREATE THE "GREENHOUSE EFFECT".

2.4.3 Depletion of Ozone Layer

The Ozone layer a thin band in the stratosphere, serves to shield the earth from the suns harmful, ultraviolet rays. Scientist in the 1970's discovered that the layer was being attacked by chlorofluorocarbons (CFC's) which are chemicals used in refrigeration, air-conditioning systems, cleaning solvents and aerosol sprays. CFC's release chlorine into the atmosphere which reacts with Ozone to produce two molecules of Oxygen. In the upper atmosphere ultraviolet light breaks off chlorine atom from a chlorofluorocarbon's molecule. Because chlorine is not affected, each chlorine molecules has the ability to destroy a large amount of Ozone for an extended period of time. The consequences of the depletion of the ozone layers are numerous. Increase in the ultraviolet lead to increased rate of skin cancer and cataracts and also reduce the ability of the human immune systems to respond to infections. Also, it affects the growth rates of oceanic plankton, which is the base of all marine food chains. This leads to increase in the CO_2 presence in the atmosphere and hence alleviate global warming. Even if CFC use were discontinued, the chlorine already released into the atmosphere would continue to destroy the ozone layers for many decades. With industrialization and modernization, there is reason to believe the destruction will continue to increase well beyond the century and hence, this will shorten human lives (Boloion, 1991).

2.5 Heat Effects on Soil

The soil mantle of the earth is indispensable for the maintenance of plant's life, affording mechanical support and supplying nutrients and water, also soil constitutes a major storage location for heat acting as a sink for energy during the day and a source to the atmosphere at night. Soil temperature is one of the most critical factors that influence important physical, chemical and biological processes in soil and plant science. Plant species however vary widely depending on the soil temperature dependent. The same is true for the following processes, organic matter decomposition and materialization, other microbial rate processes such as biodegradation of pesticides and other organic chemicals. Their intensity of change varies with the temperature (William, 1991). Soil temperature affects plant growth first during seed germination. Although seeds of different plants vary in their ability to germinate at low temperatures, all species show a marked decrease in germination rate in soils with low surface temperature (Russel, 1973). Plant growth after germination is also influenced by soil temperature. Metabolically regulated plant processes, such as water and nutrient update, can be diminished below optimum rates at both low and high temperature, resulting in temperature-dependent growth and yield patterns for example, corn yields were observed to increase almost linearly as a function of soil, temperature at 100cm between 15^{0}C – 25^{0}C, above 25^{0}C, the yield reduces (Allmaras and Burrows, 1964). Tuber and potatoes develop best with soil temperatures between 25^{0}C – 30^{0}C (Nyle, 1990). Heat from gas flares coupled with solar radiation fails on the soil hereby heating it up. Though the increased heat on the soil helps reduce diseases of vegetables and fruits and insects generally, it may not be suitable for some plants and crops to survive, hence rendering such land unsuitable for cultivation as in the charring of vegetation with associated loss of economic and mechanical plant (Alakpodia, 1980). In most cases, the villagers also complain of "internal heat" due to the cumulative effect of long exposure to radiant heat and this account generally for the loss in yield of crops some metres away. However, plants play an important role in taken in the CO_2 released into the atmosphere and when they are destroyed by the heat radiated from the flare, the ecosystem becomes unbalanced and the human race is affected adversely.

2.6 Mathematical Modelling and Simulation

A model is a simple representation of a system or process, which enhances easy understanding to be able to control the behaviour of the system. Simulating is the techniques of constructing and running of a model of real systems to be able to study its behaviour without disrupting the environment of the system. Mathematical models represent the mathematical aspect of system or process, both physical and chemical phenomena taking place in the system. Since a model retains the physical properties of a system, it provides therefore the simplest possible description of system which is exact, scaled down replica of the prototype at the same time retaining its character (William, 1995). Modelling and simulation go along together that is they are inseparable procedures, which include complex activities associated with the constructing of model representing real processes and experimentation with models to obtain data on the behaviour of the system being modelled. Modelling deals primarily with the relationship between and simulation, while the model time response is a reflection of the stimulant effect on the process output. Mathematical modelling and simulation by computer now find application in solving different types of practical problems. The purpose of studying systems through the modelling and simulation approach is to achieve some goals without operating real processes (James D.J, McDonald J.J and Stanley H, 1981). The goals area as follows;

1. To verify models obtained in some ways.
2. To test the sensitivity of system parameters
3. To estimate process variables which are not directly measurable.
4. To optimize system behaviour and efficient fault diagnose
5. To improve the understanding of some mechanism in the process of being studied.

CHAPTER THREE

3.0 CONCEPTUALIZATION IN MODELLING TECHNIQUE

Since a model is an abstraction of the real system one must have a better understanding and should be able to analyze the behaviour of such process. For this to be achieved there is need for analysis and understanding mathematical representation of the physical and chemical phenomena taking place in such a system or process. And basic assumptions were used in the development of the mathematical equation based on the fact that gas plants and flow stations in the Niger-Delta area operate throughout on a twenty-four hourly basis hence continuously flaring gas thereby contributing to the content of sulphur, carbon and nitrous oxide in the atmosphere.

The assumptions taken are as follows below:

1. Heat from flare is absorbed by the soil, part is used to vaporize water and rest is reflected back.
2. The area is a tropical forest as in the case of Niger-Delta.
3. The area is assumed to be a bed of soil i.e. soil of constant heat capacity.
4. Combustion in incomplete in air.
5. Different volume of gases is flared by the various stations.
6. The stack gas molecular weight is essentially the same as that of air (which is typical for a combustion flue gas).
7. It was assumed the flame is tilted 45^0 from the vertical

3.1 MATHEMATICAL MODELLING OF SOIL TEMPERATURE DUE TO GAS FLARING.

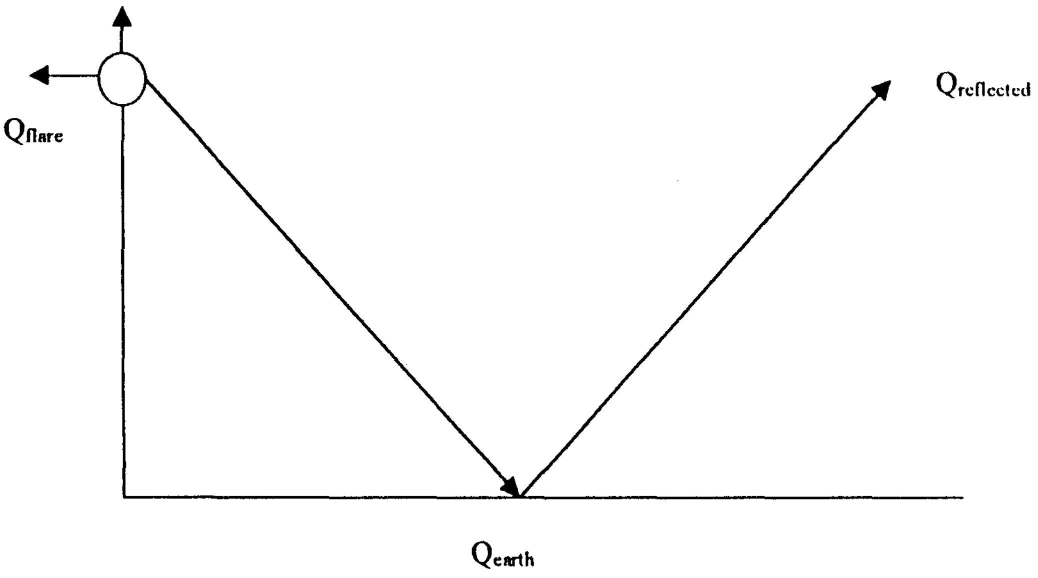


Figure: Schematic diagram of heat radiated from a flare state (Odigure and Abdulkareem, 2000)

$Q_f = Q_{flare}$ = heat from flare gas

$Q_e = Q_{earth}$ = heat absorbed by earth

$Q_r = Q_{reflected}$ = heat from flare reflected.

So taking heat balance from the above figure 1

$Q_f = Q_e + Q_r$ ----------1

But;

$Q_e = Q_{soil} + Q_{vapour}$ ----------2

Where: $Q_{soil} = Q_s$ = heat retained by soil

$Q_{vapour} = Q_v$ = heat used in vaporizing water

So putting (2) into (1) gives;

$Q_f = Q_s + Q_v + Q_r$ ... (3)

Making Q_r the subject of the formula gives;

$Q_r = Q_f - Q_s - Q_v$ ... (4)

From steward's correlating equation:

$L = 0.8632 Q_f^{0.4} N^{I}$ ... (5)

Here L = flame length

N^{I} = a combustion parameter

$$= \frac{\left(r + w\rho_a \big/ \rho\right)^{0.4}}{(1-W)(NHV)^{0.4}} \text{....(6)}$$

w = a combustion parameter

$$= \left(rcpT_a'\right) \big/ \left(rcpT_a' + NHV\right) \text{.....(7)}$$

NHV = flared gas net heating value, Btu/lb

Converting it to S.I unit which is Joules /m gives;

$$NHV = \frac{MC\theta}{x} \text{...(8)}$$

Where $\theta = (T_s - T_{st})$ ... (9).

Putting (9) into (8) becomes:

$$\text{NHV} = \frac{MC(T_s - T_{st})}{x} \text{...(10)}$$

According to API publication with the assumption that the flame is tilted at 45^0, we have;

$Hfv = L(\sin 45^0) = 0.707L$

$$= \frac{hfv}{0.707}$$

$$l = 1.414\ hfv \quad ...(11)$$

$$hfv = 0.0042\ Qf^{0.478} \quad ...(12)$$

Putting (12) into (11) we have;

$L = 1.414 \times 0.0042\ Qf^{0.478}$

$L = 0.0059\ Qf^{0.487}$ ... (13)

Equating (13) into (5) gives;

$0.0059\ Qf^{0.487} = 0.8632\ Qf^{0.4}N^{1}$

$$Q_f^{0.487} = \frac{0.8632}{0.0059} Q_f^{0.4} N^{1}$$

$Q_f^{0.487} = 145.31\ Q_f^{0.4}N^{1}$

Dividing both sides by $Q_f^{0.4}$

$Q_f^{0.487-0.4} = 145.31\ Q_f^{0.4-0.4}N^{1}$

$Q_f^{0.087} = 145.31N^{1}$ . . (14)

Putting equation (6) into (12) gives;

$$Q_f^{0.078} = \frac{145.3(r + W\rho a/\rho)^{0.4}}{\left(\frac{MC0}{X}\right)^{0.4}(1-W)} \quad . \quad . \quad . (15)$$

Putting equation (7) into (15) gives;

$$Q_f^{0.078} = \frac{145.3\left(r + \left(\frac{\left(\frac{(rCpT_a)}{rCpT_a + \frac{MC\theta}{X}} \right)}{\rho} \right) \rho_a \right)^{0.4}}{\left(\frac{MC\theta}{X} \right)^{0.4} \left(\frac{rCpT_a + \frac{MC\theta}{X} - rCpT_a}{rCpT_a + \frac{MC\theta}{X}} \right)}$$

$$Q_f^{0.078} = 145.3 \frac{\left(r \left(\frac{\left(rCpT_a + \frac{MC\theta}{X} + rCpT_a\rho_a \right)}{\left(rCpT_a + \frac{MC\theta}{X} \right)\rho} \right) \right)^{0.4}}{\left(\frac{MC\theta}{X} \right)^{0.4} \left[\frac{\frac{MC\theta}{X}}{rCpT_a + \frac{MC\theta}{X}} \right]}$$

$$= \frac{145.3 \left(\frac{rCrCpT_a + \frac{MC\theta}{X} + rCpT_a\rho_a}{\rho} \right)^{0.4} \cdot \frac{1}{\left(rCpT_a + \frac{MC\theta}{X} \right)^{0.4}}}{\left(\frac{MC\theta}{X} \right)^{0.4} \left[\frac{MC\theta}{X} / rCpT_a + \frac{MC\theta}{X} \right]}$$

$$Q_f^{0.078} = \frac{145.3 \left(\frac{\left(r \left(rCpT_a + \frac{MC\theta}{X} + rCpT_a\rho_a \right) \right)^{0.4}}{\rho} \right)}{\left(\frac{MC\theta}{X} \right)^{0.4} \left(\frac{\frac{MC\theta}{X}}{rCpT_a} + \frac{MC\theta}{X} \right) \left(rCpT_a + \frac{MC\theta}{X} \right)^{0.4}}$$

$$Q_f^{0.078} = \frac{145.3\left(\frac{\left(r\left(rCpT_a + \frac{MC\theta}{X} + rCpT_a\rho_a\right)\right)^{0.4}}{\rho}\right)}{\left(\frac{MC\theta}{X}\right)^{0.4}\left(\frac{MC\theta}{X}\right)\left(rCpT_a + \frac{MC\theta}{X}\right)^{1}\left(rCpT_a + \frac{MC\theta}{X}\right)^{0.4}}$$

$$\frac{18}{100} \times 1 \times \frac{E}{100} = 0.0018E$$

$$Q_f^{0.078} = \frac{145.3\left(r\left(\left(rCpT_a + \frac{MC\theta}{X} + rCpT_a\rho_a\right)\right)^{0.4}\right)}{\left(\frac{MC\theta}{X}\right)^{1.4}\left(rCpT_a + \frac{MC\theta}{X}\right)^{0.6}(\rho)^{0.4}}$$

$$Q_f^{0.078} = \frac{145.3\left(rCpT_a(r) + r\left(\frac{MC\theta}{X}\right) + rCpT_a\rho_a\right)^{0.4}}{\left(\frac{MC\theta}{X}\right)^{1.4}\left(rCpT_a + \frac{MC\theta}{X}\right)^{0.6}(\rho)^{0.4}}$$

Introducing log to both sides gives;

$$Log\, Q_f^{0.078} = Log\left[\frac{145.3\left(rCpT_a(r) + r\left(\frac{MC\theta}{X}\right) + rCpT_a\rho_a\right)^{0.4}}{\left(\frac{MC\theta}{X}\right)^{1.4}\left(rCpT_a + \frac{MC\theta}{X}\right)^{0.6}(\rho)^{0.4}}\right]$$

$$Log\, Q_f^{0.078} = Log\left[\frac{145.3\left((rCpT_a(r + \rho_a)) + r\left(\frac{MC\theta}{X}\right)\right)^{0.4}}{\left(\frac{MC\theta}{X}\right)^{1.4}\left(rCpT_a + \frac{MC\theta}{X}\right)^{0.6}(\rho)^{0.4}}\right]$$

$$Log\,Q_f^{0.078} = Log\left[\frac{145.3\left(\frac{(rCpT_a(X(r+\rho_a))+r(MC\theta))}{X}\right)^{0.4}}{(MC\theta)^{1.4}X^{1.4}X^{+0.6}(rCpT_a+MC\theta)^{0.6}(\rho_s)^{0.4}}\right]$$

$$Log\,Q_f^{0.078} = Log\left[\frac{145.3X^{-0.4+0.8}(rCpT_aX(r+\rho_a)+r(MC\theta))^{0.4}}{(\rho)^{0.4}(rCpT_aX+MC\theta)^{0.6}(MC\theta)^{1.4}}\right]$$

$$Log\,Q_f^{0.078} = Log\left[\frac{145.3X^{0.4}(rCpT_aX(r+\rho_a)+r(MC\theta))^{0.4}}{(\rho)^{0.4}(MC\theta)^{1.4}(rCpT_aX+MC\theta)^{0.6}}\right]$$

$$Log\,Q_f^{0.078} = Log\left[\frac{145.3X^{0.4}(rCpT_aX(r+\rho_a)+r(MC\theta))^{0.4}}{(\rho)^{0.4}(MC\theta)^{1.4}(rCpT_aX+MC\theta)^{0.6}}\right]-$$

let the right hand side be represented by log A, hence;

log Q_f = Log A/0.078

$$Q_f = {}_{10}\log\frac{A}{0.078} \qquad (16)$$

$$Qv = MwCw\int_{Tst}^{Ts} fdt + Mw\lambda w$$

$$Qv = MwCw\,(T_s - T_{st}) + Mw\lambda w \qquad (17)$$

Where

Mw = Mass of Water

Cw = Specific heat capacity of water

λw = Latent heat of vaporization of water

$$Qs = MsCs\,(T_s - T_{st}). \qquad (18)$$

Qs = Heat retained by soil

Ms = Mass of soil

Cs = Specific heat capacity of soil.

Putting equation (16), (17) and (18) into (4)

$$Qr = \frac{LogA}{_{10}0.078} - MsCs(T_s - T_{st}) - M_w C_w (T_s - T_{st}) - Mw\lambda w \quad \ldots(19)$$

Albedo shows that certain fraction of heat radiated from the source strike the receiving surface (Doostarger, 1991), hence.

$$Qc = \alpha Qf(1-a)$$

a = albedo constant = 0.31 for tropical forest

α = Absorptivity factor which varies with distance. Therefore,

$$\alpha Qr(1-a) = MwCw(T_s - T_{st}) + Mw\lambda w + MsCs(T_s - T_{st}) \ldots\ldots\ldots(19)$$

Hence,

$$Qr = \frac{\log A}{_{10}0.078} - \alpha Qr(1-a)) \quad . \quad . \quad .(20)$$

During gas flaring, there is release of large quantity of $C0_2$ rather than other gases such as those like sulphur and nitrogen oxides which are assumed negligible because of their content in associated gas being flared is so small. The total hydrocarbon content of associated is about 99.73% (Abdulkareem S. 2004) and the major hydrocarbons are shown below.

Table 3.11 Composition of associated gas in crude oil

Composition	% mass
CH_4	47
C_2H_6	18
C_3H_8	20
C_4H_{10}	5
C_5H_{12}	9
Others	<1

From the assumption that combustion is incomplete in air the amount of CO_2 released by burning 1 gram of associated gas can be calculated from stoichiometry as follows.

$$2CH_4 \rightarrow \tfrac{7}{2}O_2 \rightarrow CO_2 + CO + 4H_2O$$
$$C_2H_6 \rightarrow 3O_2 \rightarrow CO_2 + CO + 3H_2O$$
$$C_3H_8 \rightarrow 4O_2 \rightarrow CO_2 + 2CO + 4H_2O$$
$$C_4H_{10} \rightarrow 5O_2 \rightarrow CO_2 + 3CO + 5H_2O$$
$$C5H_{12} \rightarrow \tfrac{13}{2}O_2 \rightarrow 2CO_2 + 3CO + 6H_2O$$

Considering the heat released using a basis of 1m^3 of flare gas, we multiply out Qf by efficiency.

To calculate for our efficiency, we would consider CO_2, CO and H_2O, since they all add heat to the soil.

Considering for CO_2 first;

Using a basis of 1m^3 of gas being flared for CO_2, from table 3.11:

$CH_4 = 47\%$

$$\Rightarrow \frac{47}{100} \times 1m^3 = 0.47m^3$$

Let E = Efficiency of stack

$$\Rightarrow \frac{E}{100} \times 0.47 = 0.047E(m^3)$$

From the stoichiometry;

2 moles of CH_4 1 mole of CO_2

$$0.0047E \text{ of } CH_4 \rightarrow \frac{0.0047}{2}$$
$$= 0.00235E(m^3)$$

For C_2H_6;

Similarly from table C_2H_6;

$$\frac{18}{100} \times 1 \times \frac{E}{100} = 0.0018E$$

Hence,

1 mole of $C_2H_6 \longrightarrow$ 1mole at CO_2

0.0018E of $C_2H_6 \longrightarrow$ 0.0018E

For C_3H_8

From table C_3H_8 = 20%

$$\Rightarrow \frac{20}{100} \times \frac{Es}{100} = 0.002E$$

For C_4H_2;

From table $C_4H_{10} \longrightarrow$ 1 mole of CO_2

0.0005Es $\longrightarrow$ 0.0005E

For C_5H_{12};

From table, C_5H_{12} = 9

$$\Rightarrow \frac{7}{100} \times \frac{E}{100} 0.0009E$$

Hence, from the reaction;

1 mole of $C_5H_{12} \longrightarrow$ 2 moles of CO_2

0.0009Es $\longrightarrow$ 2 X 0.0009

= 0.0018E

Therefore the total amount of CO_2 is;

= (0.00235 + 0.0018 + 0.002 + 0.0005 + 0.0018)E

= 0.00845E

Similarly, following the same procedure to calculate for CO using a basis of $1m^3$

$CH_4 \longrightarrow 0.00235E$

$C_2H_6 \longrightarrow 0.0018E$

$C_3Hg \longrightarrow 0.004E$

$C_4H_{10} \longrightarrow 0.0015E$

$C_5H_{12} \longrightarrow 0.0027Em^3$

Total amount of CO

= (0.00235 + 0.0018 + 0.004 + 0.0015 + 0.0027) E

= $0.01235Em^3$

Hence, for H_2O

$CH_4 \longrightarrow 0.0094E$

$C_2H_6 \longrightarrow 0.0054E$

$C_3Hg \longrightarrow 0.008E$

$C_4H_{10} \longrightarrow 0.0025E$

$C_5H_{12} \longrightarrow 0.0054E$

Total amount of $H_2O \longrightarrow 0.0307E\ m^3$

Total amount of CO_2, CO, and H_2O in the flare gas

⇨ $0.00845 + 0.01235 + 0.0307 = 0.0515Em^3 = 0.052$

So considering a basis of 1 m^3 from the flared source equation (20) becomes

$$Qr = 0.052E\left(\frac{LogA}{{}_{10}0.078}\right) - \alpha Qr(1-a)$$

$$0.052E\left(\frac{LogA}{{}_{10}0.078}\right) = Qr + \alpha(Qr)(1-a))$$

$$10\frac{LogA}{0.078} = \frac{Qr + \alpha(Qr)(1-a)}{0.52E}$$

$$10\frac{LogA}{0.078} = \frac{Qr}{0.052E} + \frac{\alpha(Qr)(1-a)}{0.052E}$$

Introducing log to both sides;

$$\frac{LogA}{0.078} = Log\left(\frac{Qr}{0.052E}\right) + Log\left(\frac{\alpha(Qr)(1-a)}{0.052E}\right)$$

$$\frac{LogA}{0.078} = \log\left(\frac{Qr(\alpha Qr)(1-a)}{0.0027E^2}\right)$$

$$12.82LogA = Log\left(\frac{\alpha Qr^2 - \alpha Qr^2 a}{0.0027E^2}\right)$$

$$\text{let } K_1 = \frac{\alpha Qr^2 - \alpha Qr^2 a}{0.0027E^2}$$

$$\therefore 12.82LogA = LogK1$$

Log A = Log $K1^{0.078}$

A = $K_1^{0.078}$

$$K_1^{0.078} = \left[\frac{X^{0.4}(145.3)(rCpT_a[X(r+\rho_a)]) + rmc(\theta)^{0.4}}{(\rho)^{0.4}(MC\theta)^{1.4}(rCpT_aX + MC\theta)^{0.6}}\right]. \quad . \quad . (21)$$

Where,

θ = $T_s - T_{st}$

T_s = Temperature of flare stack

T_{st} = Temperature of the soil

Introducing θ into equation (21) gives

$$K_1^{0.078} = \left[\frac{X^{0.4}(145.3)\left(rCpT_a\left[X\left(r+\rho_a\right)\right]\right) + rmc\left(T_s - T_{st}\right)^{0.4}}{(\rho)^{0.4}(MC\,\theta)^{1.4}\left(rCpT_aX + MC\left(T_s - T_{st}\right)\right)^{0.6}} \right]$$

Let K$_2$ = $\left(rCpT_a\left[X\left(r+\delta_a\right)\right]\right)$, K$_3$ = X$^{0.4}$(145.3), K$_4$ = rCpT$_a$X

$$K_1^{0.078} = \frac{K_3\left[K_2 + rmc\left(T_s - T_{st}\right)^{0.4}\right]}{(\rho)^{0.4}(MC\theta)^{1.4}\left(T_s - T_{st}\right)^{1.4}\left(K_4 + MC\left(T_s - T_{st}\right)\right)^{0.6}} \qquad \text{..........} \qquad (22)$$

Let

$$\frac{K_1^{0.078}(\rho)^{0.4}}{K_3} = \frac{\left[K_2 + rmc\left(T_s - T_{st}\right)^{0.4}\right]}{(MC)\left(T_s - T_{st}\right)^{1.4}\left(K_4 + MC\left(T_s - T_{st}\right)\right)^{0.6}}$$

Dividing the powers by 0.4

$$\frac{K_1^{0.195}\rho}{K_3^{2.5}} = \frac{\left[K_2 + rmc\left(T_s - T_{st}\right)\right]}{\left[mc\left(T_s - T_{st}\right)\right]^{3.5}\left[K_4 + mc\left(T_s - T_{st}\right)\right]^{1.5}}$$

Let K$_5$ = $\dfrac{K_1^{0.195}(\rho)}{K_3^{2.5}}$

$\therefore$

$$K_5 = \frac{\left[K_2 + rmc\left(T_s - T_{st}\right)\right]}{\left[mc\left(T_s - T_{st}\right)\right]^{3.5}\left[K_4 + mc\left(T_s - T_{st}\right)\right]^{1.5}}$$

$$\left[mc\left(T_s - T_{st}\right)\right]^{3.5}\left[K_4 + mc\left(T_s - T_{st}\right)\right]^{1.5} = \frac{K_2 + rmcT_s}{K_5} - \frac{rmcT_{st}}{K_5}$$

Let $\dfrac{K_2 + rmcT_s}{K_5}$ = K$_6$

$$\therefore \left[mc\left(T_s - T_{st}\right)\right]^{3.5}\left[K_4 + mc\left(T_s - T_{st}\right)\right]^{1.5} = K_6 - \frac{rmcT_{st}}{K_5}$$

Introducing log to both sides;

$$\text{Log } [mc(T_s - T_{st})]^{3.5} [K_4 + mc(T_s - T_{st})]^{1.5} = \log K_6 - \log \frac{rmcT_{st}}{K_5}$$

$$3.5 \log [mc(T_s - T_{st})] - 1.5 \log [K_4 + mc(T_s - T_{st})] = \log K_6 - \log \frac{rmcT_{st}}{K_5}$$

$$3.5 \log mc + \log(T_s - T_{st})^{3.5} \log[K_4 + mc(T_s - T_{st})]^{1.5} = \log K_6 - \log \frac{rmcT_{st}}{K_5}$$

$$\text{Log}\left(\frac{(T_s - T_{st})^{3.5}}{K_4 + mc(T_s - T_{st})^{1.5}} \right) + \log \frac{rmcT_{st}}{K_5} = \log K_6 - \log MC^{3.5}$$

$$\log\left(\frac{(T_s - T_{st})^{3.5} \times rmcT_{st}}{(K4 + MC(T_s - T_{ts})^{1.5} \times K5)} \right) = \log\left(\frac{K_6}{MC^{3.5}} \right)$$

Dividing the powers by 3.5 gives;

$$\frac{(T_s - T_{st}) \times (rmcT_{st})^{0.285}}{[K4 + MC(T_s - T_{st})]^{1.43} K^{0.285}} = \left(\frac{K_6}{MC^{3.5}} \right)^{\frac{1}{3.5}} = \frac{K_6^{0.285}}{MC}$$

$$let \frac{K_6^{0.285}}{MC} = K_7$$

$\therefore$

$$\frac{(T_s - T_{st}) \times (rmcT_{st})^{0.285}}{[K_4 + MC(T_s - T_{st})]^{1.43} K^{0.285}} = K_7$$

$$(T_s - T_{st})\times(rmc)^{0.285}T_{st}^{0.285} = K_5^{0.285}\times K_7\times[K_4 + MC(Ts - T_{st})]^{0.4}$$

$let\ K_5^{0.285}\times K_7 = K_8$

hence,

$$(T_s - T_{st})\times(rmc)^{0.285}T_{st}^{0.285} = K_8[K_4 + MC(T_s - T_{st})]^{0.43}$$

$$T_s(rmc)^{0.285}T_{st}^{0.285} - T_{st}(rmc)^{0.285}T_{st}^{0.285} = K_8\,[K_4 + MC(Ts - T_{st})]^{0.43}$$

$$T_s(rmc)^{0.285}T_{st}^{0.285} - (rmc)^{0.285}T_{st}^{1.285} = K_8[K_4 + MC(Ts - T_{st})]^{0.43}$$

Dividing the powers by 0.43 gives;

$$T_s^{2.3}(rmc)^{0.7}T_{st}^{0.7} - (rmc)^{0.7}T_{st}^{3} = K_8^{2.3}[K_4 + MC(T_s - T_{st})]$$

$$T_s^{2.3}(rmc)^{0.7}T_{st}^{0.7} - (rmc)^{0.7}T_{st}^{3} = K_8^{2.3}K_4 + K_8^{2.3}MC(T_s - T_{st})$$

$let\ \mathrm{K}_8^{2.3}K_4 = K_9$

$\therefore$

$$T_s^{2.3}(rmc)^{0.7}T_{st}^{0.7} - (rmc)^{0.7}T_{st}^{3} = K_9 + K_8^{2.3}MC(T_s - T_{st})$$

Taking log of both sides gives;

$$\log T_s^{2.3}(rmc)^{0.7}T_{st}^{0.7} - \log(rmc)^{0.7}T_{st}^{3} = \log K_9 + \log K_8^{2.3}MC(T_s - T_{st})$$

$$\log\left[\frac{T_s^{2.3}(rmc)^{0.7}T_{st}^{0.7}}{(rmc)^{0.7}T_{st}^{3}}\right] = \log K_9 + \log K_8^{2.3}MCT_s - \log MCK_8^{2.3}T_{st}$$

$$\log\left[\frac{T_s^{2.3}T_{st}^{0.7}}{T_{st}^{3}}\right] = \log K_9\left(K_8^{2.3}MCT_s\right) - \log K_8^{2.3}MCT_{st}$$

$let\ K_9\left(K_8^{2.3}MCT_s\right) = K_{10}$

$\therefore$

$$\log\left[\frac{T_s^{2.3}T_{st}^{0.7}}{T_{st}^{3}}\right] = \log K_{10} - \log K_8^{2.3}MCT_{st}$$

$$\log\left[T^{2.3}T_{st}^{0.7}T_{st}^{-3}\right]\log K_{10} - \log K_8^{2.3}MCT_{st}$$

$$\log\left[T_s^{2.3}T_{st}^{-2.3}\right] = \log K_{10} - \log K_8^{2.3}MCT_{st}$$

$$\log\left[T_s^{2.3}T_{st}^{-2.3}\right]K_8MC = Log K_{10}$$

$$\log(T^{2.3}T_{st}^{-1.3}K_8MC) = Log K_{10}$$

$$T_s^{2.3}T_{st}^{-1.3}K_8MC = K_{10}$$

$$T_{st}^{-1.3} = [K_{10}]/T_s^{2.3}\ K_8MC$$

$$T_{st} = \left[[K_{10}]/T_s^{2.3}\ K_8MC\right]^{-1/1.3}$$

$$\mathrm{T_{st}} = \left[[K_{10}]/T_s^{2.3}\ K_8MC\right]^{-0.77}$$

$$T_{st} = \left[K_{10}T_s^{-2.3}K_8\ {}^{2.3}(MC)^{1}\right]^{0.7}$$

Where $M = \rho V$

ρ = density of flare

V = Volume of flare

Equation (23) is the modelling equation for the effect of gas flaring on soil temperature and all parameters are defined as follows:

r = stoichiometric flow rate

Cp = specific heat capacity of air (kg/kmol k)

T_a = ambient air temperature (k)

x = distance from the flare source (m^3)

ρ_a = density of air (kg/m^3)

ρ = density of flare gas (kg/m^3)

V = volume of flare gas (m^3)

C = specific heat capacity of flare gas (kg/kmol k)

T_{st} = temperature of stack (k)

E = stack efficiency

Q_r= heat radiated (kw/m2)

a = albedo constant

α = absorbtivity constant which varies with distance.

T_{st} = soil temperature (k)

CHAPTER FOUR

4.0 EXPERIMENTAL ANALYSIS.

The experimental method employed in this project is aimed at analysing and determining the resultant effect of gas flaring on the soil temperature in the Niger-Delta of Nigeria. This method is specifically employed to determine the soil temperature considering various parameters like distance from the flare point, stack efficiency, volume of the gas flared and the absorbtivity factor which depends upon distance, in conjunction with the nature of microbial and plants growth under these conditions. The experiments mentioned were performed by the process industries situated in the Niger-Delta area where the data were gotten from.

The explanation of the experimental method is to enhance understanding of the proposed modelling technique and to verify validity.

4.1 EXPERIMENTAL PROCEDURE

The experiment is generally aimed at obtaining the temperature of the soil at about 100m depths. Temperatures are taken at different distances of 20, 40, 60,100,500 and 2000 metres away from the flare point. The results obtained are then recorded. These results however will be used to test the conformity with the simulated results using visual basic programme.

4.2 EXPERIMENTAL RESULTS

TABLE 4.2.1 PARAMETER SOIL TEMPERATURE (^{0}C)

STATION A

MONTHS	YEAR	DISTANCE (m)						
		20	40	60	100	200	500	1000
OCTOBER	1997	30.1	26.8	26.4	25.52	25.4	26.5	26.4
NOVEMBER	1997	31.2	28.4	28.4	27.4	27.0	28.0	27.8
DECEMBER	1997	31.2	28.4	28.4	27.4	27.0	28.0	27.8
JANUARY	1998	31.9	30.0	30.2	29.2	28.9	28.0	29.2
FEBRUARY	1998	37.6	34.4	32.4	32.4	28.8	31.0	30.4
MARCH	1998	36.6	35.0	34.5	32.5	29.4	34.5	33.8
APRIL	1998	38.0	36.0	36.0	29.2	29.5	30.0	30.0
MAY	1998	33.1	32.6	32.6	30.2	29.8	29.2	29.0
JUNE	1998	35.1	30.0	30.0	30.0	30.0	31.0	30.0
JULY	1998	30.5	26.5	26.5	25.2	25.0	25.1	25.0
AUGUST	1998	27.9	27.9	27.9	28.3	28.1	27.9	27.2
SEPTEMBER	1998	27.8	25.8	25.5	23.5	23.0	24.5	24.1

TABLE 4.2.2 PARAMETER SOIL TEMPERATURE (^{0}C)

STATION B

MONTHS	YEAR	DISTANCE (m)						
		20	40	60	100	200	500	1000
OCTOBER	1997	28.4	28.4	28.5	27.2	28.2	27.8	26.8
NOVEMBER	1997	30.1	29.2	30.6	31.3	30.4	29.1	28.8
DECEMBER	1997	32.1	30.3	29.3	29.4	29.0	28.9	30.2
JANUARY	1998	30.8	30.7	30.3	30.7	30.3	28.3	28.3
FEBRUARY	1998	34.3	32.2	32.1	31.8	31.3	31.1	31.5
MARCH	1998	35.1	33.9	33.1	33.2	30.7	30.1	30.8
APRIL	1998	37.0	35.6	34.6	35.1	34.4	34.4	34.5
MAY	1998	32.9	32.8	33.2	33.0	33.7	33.7	33.
JUNE	1998	28.0	26.8	26.3	25.3	26.3	26.3	26.0
JULY	1998	29.2	29.0	28.3	28.3	28.8	28.8	29.1
AUGUST	1998	29.0	30.0	29.0	29.0	28.0	28.5	28.0
SEPTEMBER	1998	32.0	28.5	28.2	27.4	28.7	27.5	27.0

TABLE 4.2.3 PARAMETER SOIL TEMPERATURE (^{0}C)

STATION C

MONTHS	YEAR	DISTANCE (m)						
		20	40	60	100	200	500	1000
OCTOBER	1997	28.6	28.5	29.1	28.9	30.2	26.8	26.0
NOVEMBER	1997	29.4	28.8	28.8	30.2	30.6	27.0	27.1
DECEMBER	1997	28.5	28.6	28.9	28.8	29.5	27.4	26.5
JANUARY	1998	27.7	26.6	26.5	27.5	28.0	27.1	27.8
FEBRUARY	1998	34.7	31.9	31.5	30.9	30.4	29.0	27.4
MARCH	1998	36.6	33.5	33.8	34.3	32.9	33.0	28.8
APRIL	1998	35.1	34.5	33.5	31.8	34.2	31.2	29.9
MAY	1998	32.1	32.5	32.6	31.6	32.6	29.9	30.7
JUNE	1998	28.1	27.0	26.3	25.0	26.0	25.3	23.0
JULY	1998	27.1	26.5	26.5	25.1	25.2	25.4	25.3
AUGUST	1998	28.3	28.8	29.0	28.0	28.3	26.6	26.0
SEPTEMBER	1998	35.0	32.1	33.5	31.0	30.0	29.0	31.0

TABLE 4.2.4 PARAMETER SOIL TEMPERATURE (^0C)

STATION D

MONTHS	YEAR	DISTANCE (m)						
		20	40	60	100	200	500	1000
OCTOBER	1997	28.0	27.1	27.6	28.0	27.2	26.6	27.9
NOVEMBER	1997	29.5	29.5	29.2	29.5	29.2	28.9	29.7
DECEMBER	1997	-	-	-	-	-	-	-
JANUARY	1998	25.4	24.6	25.4	25.8	24.6	24.8	26.0
FEBRUARY	1998	-	-	-	-	-	-	-
MARCH	1998	34.2	34.5	34.2	33.2	33.4	31.6	34.4
APRIL	1998	-	-	-	-	-	-	-
MAY	1998	33.7	34.9	35.0	34.9	34.7	34.8	33.2
JUNE	1998	29.5	31.0	29.0	30.5	30.0	31.0	31.6
JULY	1998	-	-	-	-	-	-	-
AUGUST	1998	-	-	-	-	-	-	-
SEPTEMBER	1998	26.0	25.0	24.0	24.5	25.5	24.5	25.0

CHAPTER FIVE

5.0 INPUT DATA

TABLE 5.0.1 Variable Parameters Used In Simulating the Result: Station 1

Month	V × 10^{-3} (m^3/month)	Ta (^{0}C)	Ts (K)
January	2817.84	37	950
February	24118.28	37.5	950
March	21634.54	37.8	1100
April	31774.66	36.7	1000
May	21706	31.2	900
June	32608.15	34	900
July	26710.53	33.4	1050
August	32508.15	37.3	900
September	37443.25	31	1080
October	2817.84	37	950
November	21233.68	34	1000
December	26710.53	33.5	1100

TABLE 5.0.2 Variable Parameters Used In Simulating the Result: Station 2

Month	V × 10^{-3} (m^3/month)	Ta (^{0}C)	Ts (K)
January	2601.84	31.5	1160
February	2328.82	31.5	1000
March	2356.5	37.5	900
April	2401.62	38	900
May	1904.18	38	1100
June	2230.28	29.8	1000
July	2434.57	34.2	1050
August	2508.68	30	1000
September	2334.82	30.4	980
October	2412.72	31	900
November	2208.54	32	1000
December	2608.75	35	900

TABLE 5.0.3 Variable Parameters Used In Simulating the Result: Station 3

Month	$V \times 10^{-3}$ (m^3/month)	Ta (^0C)	Ts (K)
January	7769.6	30	900
February	2328.82	31.5	1000
March	2356.5	37.5	900
April	8648.28	35	750
May	13393.57	33	1100
June	11663.38	30	850
July	10864.95	34.6	980
August	12460.58	33.5	900
September	10872.86	31.2	1100
October	8560	1000	34
November	12125.14	30	780
December	13200.62	30	1000

TABLE 5.0.4 Variable Parameters Used In Simulating the Result: Station 4

Month	$V \times 10^{-3}$(m^3/month)	Ta (^0C)	Ts (K)
January	15436.36	37.5	1000
February	13948.68	35.5	1100
March	15436.73	36.5	900
April	15210.62	33.5	1100
May	14552.02	37	1000
June	12273.48	33.6	950
July	12309.22	34.6	900
August	14310.52	30	1050
September	15400.58	32.1	1100
October	12342.26	33	850
November	14610.48	900	36
December	14622.8	950	34.5

5.1 CONSTANT PARAMETERS

$C_P = 2200$

$C = 190$

$r = 15$

$\rho_a = 1.289$

And ρ is calculated using the formula below;

$\rho = (Ta * \rho_a) / Ts$

All parameters have been defined earlier on.

5.2 MODELLING SIMULATION RESULTS

Simulation is a means by which the behaviour and operation of the system of a model is studied using computer codes. The model equation were simulated using Visual BASIC programme and results obtained for soil temperature at various distances from the point of flare are as shown in the table below.

5.3 SIMULATION RESULTS

Table 5.3.1

Various Soil Temperatures as a result of Gas Flaring : Station 1

	January	February	March	April	May	June	July	August	September	October	November	December
20	32.4	156.1	128.61	205.63	381.6	223.83	164.13	224.39	234.91	32.4	131.92	159.96
40	29.18	99.1	83.56	127.1	226.55	137.38	103.64	137.7	143.64	29.18	85.43	101.28
60	28	78.07	66.94	98.12	169.36	105.49	81.32	105.71	109.98	28	68.28	79.63
80	27.37	66.88	58.1	82.7	138.92	88.52	69.45	88.7	92.06	27.37	59.15	68.11
100	26.97	59.85	52.54	73.02	119.8	77.86	61.99	78.01	80.81	26.97	53.42	60.88
120	26.69	54.99	48.71	66.33	106.59	70.49	56.83	70.62	73.03	26.69	49.46	55.88
140	26.49	51.42	45.88	61.4	96.87	65.07	53.04	65.18	67.3	26.49	46.55	52.2
160	26.34	48.67	43.71	57.61	89.39	60.9	50.12	61	62.9	26.34	44.3	49.37
180	26.21	46.48	41.98	54.6	83.44	57.58	47.8	57.67	59.4	26.21	42.52	47.12
200	26.11	44.7	40.57	52.14	78.58	54.88	45.91	54.96	56.54	26.11	41.07	45.28
400	26.11	44.7	40.57	52.14	78.58	54.88	45.91	54.96	56.54	26.11	41.07	45.28
600	25.63	36.13	33.8	40.34	55.29	41.89	36.82	41.93	42.83	25.63	34.08	36.46
800	25.45	32.97	31.3	35.99	46.69	37.09	33.46	37.13	37.77	25.45	31.5	33.21
1000	25.36	31.29	29.97	33.67	42.12	34.54	31.68	34.57	35.08	25.36	30.13	31.48
1200	25.3	30.24	29.14	32.22	39.25	32.94	30.56	32.96	33.39	25.3	29.27	30.39
1400	25.25	29.51	28.56	31.21	37.26	31.84	29.78	31.85	32.22	25.25	28.68	29.64
1600	25.22	28.97	28.14	30.47	35.8	31.02	29.21	31.04	31.36	25.22	28.24	29.09
1800	25.2	28.56	27.81	29.9	34.67	30.39	28.77	30.41	30.7	25.2	27.9	28.66
2000	25.18	28.23	27.55	29.45	33.78	29.9	28.43	29.91	30.17	25.18	27.63	28.32

Table 5.3.2

Various Soil Temperatures as a result of Gas Flaring : Station 2

Distance	January	February	March	April	May	June	July	August	September	October	November	December
20	30.95	30.4	30.94	31.11	28.84	30.06	30.61	31	30.48	31.08	30.01	31.83
40	28.36	28.05	28.36	28.46	27.17	27.86	28.17	28.39	28.1	28.43	27.83	28.86
60	27.41	27.19	27.41	27.47	26.55	27.05	27.27	27.43	27.22	27.46	27.03	27.76
80	26.9	26.73	26.9	26.95	26.23	26.62	26.79	26.92	26.75	26.94	26.6	27.18
100	26.58	26.44	26.58	26.63	26.02	26.35	26.49	26.59	26.46	26.62	26.33	26.81
120	26.36	26.24	26.36	26.4	25.88	26.16	26.28	26.37	26.25	26.39	26.15	26.56
140	26.2	26.09	26.2	26.23	25.77	26.02	26.13	26.21	26.11	26.22	26.01	26.38
160	26.07	25.98	26.07	26.1	25.69	25.91	26.01	26.08	25.99	26.1	25.9	26.23
180	25.98	25.89	25.97	26	25.63	25.83	25.92	25.98	25.9	26	25.82	26.12
200	25.89	25.81	25.89	25.92	25.58	25.76	25.84	25.9	25.82	25.91	25.75	26.03
400	25.89	25.81	25.89	25.92	25.58	25.76	25.84	25.9	25.82	25.91	25.75	26.03
600	25.51	25.46	25.5	25.52	25.33	25.43	25.48	25.51	25.47	25.52	25.43	25.58
800	25.36	25.33	25.36	25.37	25.23	25.31	25.34	25.36	25.33	25.37	25.3	25.42
1000	25.29	25.26	25.29	25.29	25.18	25.24	25.27	25.29	25.26	25.29	25.24	25.33
1200	25.24	25.22	25.24	25.24	25.15	25.2	25.22	25.24	25.22	25.24	25.2	25.27
1400	25.2	25.19	25.2	25.21	25.13	25.17	25.19	25.21	25.19	25.21	25.17	25.23
1600	25.18	25.16	25.18	25.19	25.12	25.15	25.17	25.18	25.17	25.18	25.15	25.21
1800	25.16	25.15	25.16	25.17	25.1	25.14	25.15	25.16	25.15	25.16	25.14	25.19
2000	25.15	25.13	25.15	25.15	25.09	25.12	25.14	25.15	25.14	25.15	25.12	25.17

Table 5.3.3

Various Soil Temperatures as a result of Gas Flaring : Station 3

	January	February	March	April	May	June	July	August	September	October	November	December
20	55.4	54.26	57.79	64.6	80.07	78.93	70.26	82.11	66.75	57.56	84.85	82.2
40	42.18	41.54	43.53	47.38	56.13	55.48	50.58	57.28	48.6	43.4	58.83	57.33
60	37.31	36.85	38.27	41.03	47.29	46.83	43.32	48.12	41.9	38.18	49.23	48.16
80	34.71	34.35	35.47	37.65	42.59	42.23	39.46	43.24	38.34	35.4	44.12	43.27
100	33.08	32.78	33.72	35.53	39.64	39.34	37.03	40.18	36.1	33.66	40.91	40.21
120	31.95	31.7	32.5	34.06	37.6	37.34	35.36	38.07	34.55	32.45	38.69	38.09
140	31.13	30.9	31.61	32.98	36.1	35.87	34.12	36.51	33.41	31.56	37.06	36.53
160	30.49	30.28	30.92	32.15	34.94	34.74	33.17	35.31	32.54	30.88	35.81	35.33
180	29.98	29.8	30.37	31.49	34.02	33.84	32.42	34.36	31.84	30.34	34.81	34.37
200	29.57	29.4	29.93	30.95	33.28	33.1	31.8	33.58	31.27	29.89	33.99	33.6
400	29.57	29.4	29.93	30.95	33.28	33.1	31.8	33.58	31.27	29.89	33.99	33.6
600	27.58	27.49	27.78	28.36	29.68	29.58	28.84	29.85	28.55	27.77	30.08	29.86
800	26.85	26.78	26.99	27.41	28.35	28.28	27.75	28.47	27.54	26.98	28.64	28.48
1000	26.46	26.4	26.57	26.9	27.64	27.59	27.17	27.74	27	26.56	27.87	27.75
1200	26.21	26.17	26.31	26.58	27.2	27.15	26.81	27.28	26.67	26.3	27.39	27.29
1400	26.05	26.01	26.13	26.36	26.89	26.85	26.56	26.96	26.44	26.12	27.06	26.97
1600	25.92	25.89	25.99	26.2	26.67	26.63	26.37	26.73	26.26	25.99	26.81	26.73
1800	25.82	25.79	25.89	26.07	26.49	26.46	26.23	26.55	26.13	25.88	26.62	26.55
2000	25.75	25.72	25.81	25.98	26.36	26.33	26.11	26.41	26.03	25.8	26.47	26.41

Table 5.3.4

Various Soil Temperatures as a result of Gas Flaring : Station 4

	January	February	March	April	May	June	July	August	September	October	November	December
20	96.12	83.34	100.95	90.08	90.8	79.1	80.95	86.58	90.98	83.41	95.63	93.09
40	65.2	57.97	67.93	61.78	62.19	55.58	56.62	59.81	62.29	58.01	64.92	63.48
60	53.79	48.61	55.75	51.35	51.64	46.9	47.65	49.93	51.71	48.64	53.59	52.56
80	47.72	43.64	49.26	45.79	46.02	42.28	42.87	44.67	46.08	43.66	47.56	46.75
100	43.91	40.51	45.19	42.3	42.49	39.38	39.87	41.37	42.54	40.53	43.78	43.1
120	41.27	38.35	42.38	39.89	40.05	37.38	37.8	39.09	40.1	38.36	41.16	40.58
140	39.33	36.76	40.31	38.12	38.26	35.9	36.27	37.41	38.3	36.77	39.24	38.72
160	37.84	35.53	38.71	36.75	36.88	34.77	35.1	36.12	36.91	35.55	37.75	37.29
180	36.65	34.56	37.45	35.67	35.78	33.87	34.17	35.09	35.81	34.57	36.58	36.16
200	35.69	33.77	36.41	34.78	34.89	33.13	33.41	34.25	34.91	33.78	35.61	35.23
400	35.69	33.77	36.41	34.78	34.89	33.13	33.41	34.25	34.91	33.78	35.61	35.23
600	31.04	29.95	31.45	30.53	30.59	29.59	29.75	30.23	30.6	29.96	31	30.78
800	29.33	28.55	29.62	28.96	29	28.29	28.4	28.75	29.01	28.55	29.3	29.14
1000	28.41	27.8	28.65	28.12	28.16	27.6	27.69	27.96	28.17	27.8	28.39	28.27
1200	27.84	27.33	28.03	27.6	27.63	27.16	27.23	27.46	27.64	27.33	27.82	27.72
1400	27.45	27.01	27.61	27.24	27.26	26.86	26.92	27.12	27.27	27.01	27.43	27.34
1600	27.15	26.77	27.3	26.97	26.99	26.64	26.69	26.86	27	26.77	27.14	27.06
1800	26.93	26.58	27.06	26.77	26.79	26.47	26.52	26.67	26.79	26.58	26.92	26.85
2000	26.75	26.44	26.87	26.6	26.62	26.33	26.38	26.52	26.62	26.44	26.74	26.68

5.4 DISCUSSION OF RESULTS

The urbanization and industrialization of man have reached a level in which their effects have become global in nature (Boloion, 1991).Such activities as we have in the case of gas flaring and combustion of other gases not only alters the ecosystem but also affects the structures, vegetation, human health and migration.

All plants grow and reproduce in response to an interaction of dynamic and ever-changing components in their environment. Plants require favorable soil and surrounding temperature for them to survive and each species of plants have a minimal soil temperature below, which no growth of roots will occur (Nyle,1990).

Gas flaring in the Niger-Delta area pollutes the entire ecosystem thereby making environment unbearable for human lives. Also, it increases the level of he temperature of the soil to a much higher level, hence making the survival of plants and vegetation almost impossible. The plants and vegetable, which are mainly grown in this area, can tolerate temperature ranges between $16^{O}C$-$28^{O}C$ but anything higher that this affects their growth rate hence resulting in stunted growth, discoloration of green leaves and poor yield production.

On the basis of the available experimental data of soil temperature obtained at various distance up to 2000m from the flare station shown in table 4.2.1 to 4.2.4 and that of simulated values as shown in table 5.1.1 to 5.1.4, it could be observed that at an average distance of 20m, the soil temperature is above $30^{O}C$, this is due to large amount of heat released during flaring and the effect of the gas flared is felt within the radius range of 300-700m away from the flare sources depending on the volume of gas flared, wind speed and the stack height. At a distance of 700m and above, simulation result shows that the zone is safe for farming of vegetables and tubers, since they can survive soil temperature between 25°C-30°C (Nyle, 1990).

It could be observed from the simulated results shown in tables 5.1.1 to 5.1.4 that an increase in the volume of gas flared will cause an increase in soil temperature at a particular distance. Simulated results also shows that soil temperature reduces as distance increases and this could be possibly attributed to the percentage of heat absorbed by the soil at various distances.

However, there are some variations between the experimental data and simulated result and this could be due to the following reason; the assumptions made during the conceptual stage of the mathematical equation, the unpatterned nature of the experimental data which may be due to the fact that the weather was not constant, also the variation may be due to atmospheric conditions such as wind speed, humidity and temperature felt at various distance. From the soil temperature obtained, the model equation can be used in simulating the effect of gas flaring on soil temperature since it conforms with the experimental data to a great extent.

5.5 CONCLUSION

From the research work, it could be deduced that the model equation generated reasonably reflects the considered variable. Hence the simulation results conform to the experimental ones. Therefore, it can be deduced that the soil temperature at various distances depends on the volume of gas flared, stack efficiency and the absorptivity of the soil.

5.6 RECOMMENDATION

1. In the course of crude oil exploration, there should be conversion from petrol and diesel to compressed natural gas in order to promote gas utilization and hence reduce the flaring of gas to a minimum. The government should invest in the gas sector so as to reduce the magnitude of disaster caused by gas flaring activities.
2. It is advisable that farming activities should be carried at a distance of at least 800m away from the flare station. It is highly important that people are not to habitat themselves within the same range too.
3. The use of gas should be encouraged for domestic source of fuel because this will go a long way to stop the problem of deforestation since less pressure will on the use woods.
4. More laws like the 'Associated Gas Re-injection Decree No. 99' should be introduced and strictly monitored by the government to ensure that companies involved in the flaring act should adhere strictly to these laws.

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WWW.JulianPrime@dfi.gsi.gov.uk

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APPENDIX A

Visual BASIC Program

```
Private arrayV_(4), arrayVs_(4), arrayU_(4), arrayTs_(4), arrayTa_(4) As Double
Dim bisi(12) As Concent
Private i As Integer
Private V_, Es_, Vs_, Ts_, Ta_, U_ As Double
Private C_, r_, Da_, Cp_ As Double
Private x, y, z As Double
Private anSt(4, 12, 20) As Double

Private Sub Form_Load()
   Me.Width = 8610
   Me.Height = 4095
   addComboItems
   setTitle
   textFlds
End Sub
Private Function getValues(Index As Integer) As Double
   Dim row As Integer
   Dim ju As Integer
   ju = Index

   V_ = Val(V(ju%)) / (2592000)
   vol = V_
   Ts_ = (Val(Ts(ju%)) + 273)
   Ta_ = (Val(Ta(ju%)) + 273)

   C_ = Val(C(0))
   r_ = Val(r(0))
   Da_ = Val(Da(0))
   Cp_ = Val(Cp(0))

   x = 20
   For row = 0 To 9
      y = x
      z = x
      answer(row, 0) = Tst
      x = x + 20
   Next row
   x = 200
   For row = 10 To 19
      y = x
```

```
    z = x
    answer(row, 0) = Tst
    x = x + 200
  Next row
  getValues = 0
End Function
Private Sub textFlds()
  V(0).Left = station(0).Left + station(0).Width + 400
  Ts(0).Left = V(0).Left + station(0).Width + 200
  Ta(0).Left = Ts(0).Left + station(0).Width + 200

  'Ts(0).Left = U(0).Left + station(0).Width + 200
  'Ta(0).Left = Ts(0).Left + station(0).Width + 200
  'hs(0).Left = Vs(0).Left + Vs(0).Width + 200
  'Cps(0).Left = hs(0).Left + hs(0).Width + 200


  V(0).Top = station(0).Top
  Ts(0).Top = station(0).Top
  Ta(0).Top = station(0).Top

  'Ts(0).Top = station(0).Top
  'Ta(0).Top = station(0).Top
  'hs(0).Top = station(0).Top
  'Cps(0).Top = station(0).Top

  For i% = 1 To 3
    Load Check1(i%)
    Check1(i%).Visible = True
    Check1(i%).Top = station(i%).Top


    Load V(i%)
    V(i%).Left = V(i% - 1).Left
    V(i%).Top = station(i%).Top
    V(i%).Visible = True

    Load Ts(i%)
    Ts(i%).Left = Ts(i% - 1).Left
    Ts(i%).Top = station(i%).Top
    Ts(i%).Visible = True

    Load Ta(i%)
    Ta(i%).Left = Ta(i% - 1).Left
    Ta(i%).Top = station(i%).Top
    Ta(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 = station(i%).Top
        'Ta(i%).Visible = True
    Next i%

    'Dim we As Integer
    'For we = 1 To 3
    '   Check1(we).Value = 0
    'Next we


End Sub

Private Sub setTitle()
    Dim title(22) As String
    Dim ex As Integer
    title(0) = "Input Data"
    title(1) = "Volume"
    title(2) = "Ts"
    title(3) = "Ta"


    title(4) = "Ts"
    title(5) = "Ta"

    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 3
       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
       V(sta).Enabled = True
       Ts(sta).Enabled = True
       Ta(sta).Enabled = True
```

```
        'Ts(sta).Enabled = True
        'Ta(sta).Enabled = True
        'hs(sta).Enabled = True
        'Cps(sta).Enabled = True
        'Es(sta).Enabled = True
    ElseIf (Check1(sta).Value = 0) Then
        V(sta).Enabled = False
        Ts(sta).Enabled = False
        Ta(sta).Enabled = False
        'Ts(sta).Enabled = False
        'Ta(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) = 2817.84 * 10 ^ 3
    arrayV_(1) = 2601.94 * 10 ^ 3
    arrayV_(2) = 7769.6 * 10 ^ 3
    arrayV_(3) = 15436.36 * 10 ^ 3

    arrayTs_(0) = 950
    arrayTs_(1) = 1100
    arrayTs_(2) = 900
    arrayTs_(3) = 1000

    arrayTa_(0) = 37#
    arrayTa_(1) = 31.5
    arrayTa_(2) = 30#
    arrayTa_(3) = 37.5

    For i% = 0 To 3
        V(i%).Text = arrayV_(i%)
        Ts(i%).Text = arrayTs_(i%)
        Ta(i%).Text = arrayTa_(i%)
    Next i
End Sub

Private Sub Feb_Label()
    arrayV_(0) = 24118.28 * 10 ^ 3
    arrayV_(1) = 2328.82 * 10 ^ 3
    arrayV_(2) = 7874.05 * 10 ^ 3
    arrayV_(3) = 13948.68 * 10 ^ 3

    arrayTs_(0) = 950
    arrayTs_(1) = 1000
    arrayTs_(2) = 1000
    arrayTs_(3) = 1100

    arrayTa_(0) = 37.5
    arrayTa_(1) = 31.5
    arrayTa_(2) = 36.5
    arrayTa_(3) = 35.5
```

```
   For i% = 0 To 3
      V(i%).Text = arrayV_(i%)
      Ts(i%).Text = arrayTs_(i%)
      Ta(i%).Text = arrayTa_(i%)
   Next i
End Sub

Private Sub Mar_Label()
   arrayV_(0) = 21634.54 * 10 ^ 3
   arrayV_(1) = 2356.5 * 10 ^ 3
   arrayV_(2) = 8579.86 * 10 ^ 3
   arrayV_(3) = 15436.73 * 10 ^ 3

   arrayTs_(0) = 1100
   arrayTs_(1) = 900
   arrayTs_(2) = 1000
   arrayTs_(3) = 900

   arrayTa_(0) = 37.8
   arrayTa_(1) = 37.5
   arrayTa_(2) = 36.2
   arrayTa_(3) = 36.5

   For i% = 0 To 3
      V(i%).Text = arrayV_(i%)
      Ts(i%).Text = arrayTs_(i%)
      Ta(i%).Text = arrayTa_(i%)
   Next i
End Sub

Private Sub Apr_Label()
   arrayV_(0) = 31774.66 * 10 ^ 3
   arrayV_(1) = 2401.62 * 10 ^ 3
   arrayV_(2) = 8648.28 * 10 ^ 3
   arrayV_(3) = 15210.62 * 10 ^ 3

   arrayTs_(0) = 1000
   arrayTs_(1) = 900
   arrayTs_(2) = 750
   arrayTs_(3) = 1100

   arrayTa_(0) = 36.7
   arrayTa_(1) = 38#
   arrayTa_(2) = 35#
   arrayTa_(3) = 33.5
```

```
    For i% = 0 To 3
       V(i%).Text = arrayV_(i%)
       Ts(i%).Text = arrayTs_(i%)
       Ta(i%).Text = arrayTa_(i%)
    Next i
End Sub

Private Sub May_Label()
    arrayV_(0) = 21706 * 10 ^ 3
    arrayV_(1) = 1904.18 * 10 ^ 3
    arrayV_(2) = 13393.57 * 10 ^ 3
    arrayV_(3) = 14552.02 * 10 ^ 3

    arrayTs_(0) = 31.2
    arrayTs_(1) = 1100
    arrayTs_(2) = 1100
    arrayTs_(3) = 1000

    arrayTa_(0) = 31.2
    arrayTa_(1) = 38#
    arrayTa_(2) = 33#
    arrayTa_(3) = 37#

    For i% = 0 To 3
       V(i%).Text = arrayV_(i%)
       Ts(i%).Text = arrayTs_(i%)
       Ta(i%).Text = arrayTa_(i%)
    Next i
End Sub

Private Sub Jun_Label()
    arrayV_(0) = 32608.15 * 10 ^ 3
    arrayV_(1) = 2230.28 * 10 ^ 3
    arrayV_(2) = 11663.38 * 10 ^ 3
    arrayV_(3) = 12273.48 * 10 ^ 3

    arrayTs_(0) = 900
    arrayTs_(1) = 1000
    arrayTs_(2) = 850
    arrayTs_(3) = 950

    arrayTa_(0) = 34#
    arrayTa_(1) = 29.8
    arrayTa_(2) = 30#
    arrayTa_(3) = 33.6
```

```
  For i% = 0 To 3
    V(i%).Text = arrayV_(i%)
    Ts(i%).Text = arrayTs_(i%)
    Ta(i%).Text = arrayTa_(i%)
  Next i
End Sub

Private Sub Jul_Label()
  arrayV_(0) = 26710.53 * 10 ^ 3
  arrayV_(1) = 2434.57 * 10 ^ 3
  arrayV_(2) = 10864.95 * 10 ^ 3
  arrayV_(3) = 12309.22 * 10 ^ 3

  arrayTs_(0) = 1050
  arrayTs_(1) = 1050
  arrayTs_(2) = 980
  arrayTs_(3) = 900

  arrayTa_(0) = 33.4
  arrayTa_(1) = 34.2
  arrayTa_(2) = 34.6
  arrayTa_(3) = 31#

  For i% = 0 To 3
    V(i%).Text = arrayV_(i%)
    Ts(i%).Text = arrayTs_(i%)
    Ta(i%).Text = arrayTa_(i%)
  Next i
End Sub

Private Sub Aug_Label()
  arrayV_(0) = 32508.15 * 10 ^ 3
  arrayV_(1) = 2508.68 * 10 ^ 3
  arrayV_(2) = 12460.58 * 10 ^ 3
  arrayV_(3) = 14310.52 * 10 ^ 3

  arrayTs_(0) = 900
  arrayTs_(1) = 1000
  arrayTs_(2) = 900
  arrayTs_(3) = 1050

  arrayTa_(0) = 37.8
  arrayTa_(1) = 30#
  arrayTa_(2) = 33.5
  arrayTa_(3) = 30#
```

```
    For i% = 0 To 3
      V(i%).Text = arrayV_(i%)
      Ts(i%).Text = arrayTs_(i%)
      Ta(i%).Text = arrayTa_(i%)
    Next i
End Sub

Private Sub Sep_Label()
    arrayV_(0) = 37443.25 * 10 ^ 3
    arrayV_(1) = 2334.82 * 10 ^ 3
    arrayV_(2) = 10872.86 * 10 ^ 3
    arrayV_(3) = 15400.58 * 10 ^ 3

    arrayTs_(0) = 1080
    arrayTs_(1) = 980
    arrayTs_(2) = 1100
    arrayTs_(3) = 1100

    arrayTa_(0) = 31#
    arrayTa_(1) = 30.4
    arrayTa_(2) = 31.2
    arrayTa_(3) = 32.1

    For i% = 0 To 3
      V(i%).Text = arrayV_(i%)
      Ts(i%).Text = arrayTs_(i%)
      Ta(i%).Text = arrayTa_(i%)
    Next i
End Sub
Private Sub Oct_Label()
    arrayV_(0) = 2817.84 * 10 ^ 3
    arrayV_(1) = 2412.72 * 10 ^ 3
    arrayV_(2) = 8560 * 10 ^ 3
    arrayV_(3) = 12342.26 * 10 ^ 3

    arrayTs_(0) = 950
    arrayTs_(1) = 900
    arrayTs_(2) = 1000
    arrayTs_(3) = 850

    arrayTa_(0) = 37#
    arrayTa_(1) = 31#
    arrayTa_(2) = 34#
    arrayTa_(3) = 33#

    For i% = 0 To 3
```

```
      V(i%).Text = arrayV_(i%)
      Ts(i%).Text = arrayTs_(i%)
      Ta(i%).Text = arrayTa_(i%)
   Next i
End Sub

Private Sub Nov_Label()
   arrayV_(0) = 21233.68 * 10 ^ 3
   arrayV_(1) = 2208.54 * 10 ^ 3
   arrayV_(2) = 12125.14 * 10 ^ 3
   arrayV_(3) = 14610.48 * 10 ^ 3

   arrayTs_(0) = 1000
   arrayTs_(1) = 1000
   arrayTs_(2) = 780
   arrayTs_(3) = 900

   arrayTa_(0) = 34
   arrayTa_(1) = 32#
   arrayTa_(2) = 30#
   arrayTa_(3) = 36#

   For i% = 0 To 3
      V(i%).Text = arrayV_(i%)
      Ts(i%).Text = arrayTs_(i%)
      Ta(i%).Text = arrayTa_(i%)
   Next i
End Sub

Private Sub Dec_Label()
   arrayV_(0) = 26710.53 * 10 ^ 3
   arrayV_(1) = 2603.78 * 10 ^ 3
   arrayV_(2) = 13200.62 * 10 ^ 3
   arrayV_(3) = 14622.8 * 10 ^ 3

   arrayTs_(0) = 1100
   arrayTs_(1) = 900
   arrayTs_(2) = 1000
   arrayTs_(3) = 950

   arrayTa_(0) = 33.5
   arrayTa_(1) = 35#
   arrayTa_(2) = 30#
   arrayTa_(3) = 34.1

   For i% = 0 To 3
```

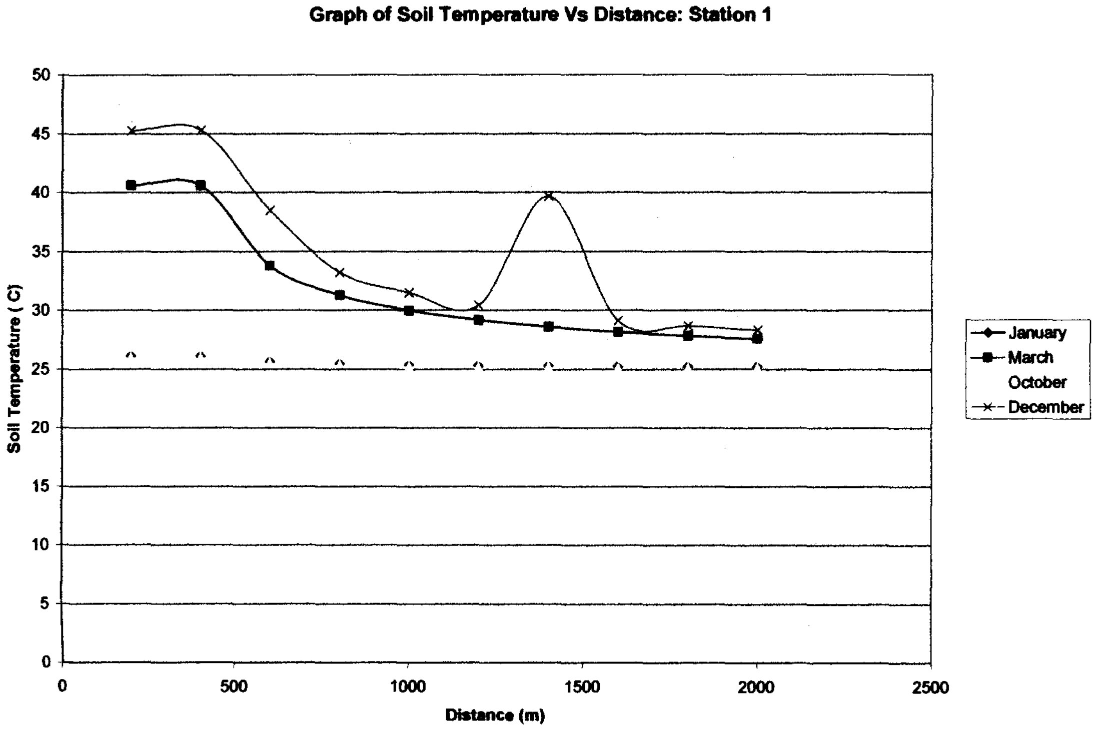
```
      V(i%).Text = arrayV_(i%)
      Ts(i%).Text = arrayTs_(i%)
      Ta(i%).Text = arrayTa_(i%)
   Next i
End Sub

Private Sub reset_Click()
   For i = 0 To 1
      V(i%).Text = ""
      Ta(i%).Text = ""
      Ts(i%).Text = ""
   Next i
End Sub

Private Sub simulate_Click()
   On Error GoTo mineError

retry:
   Dim select_, chec As Integer
   select_ = sel(month.Text)
   selMonth = month.Text
   If select_ = 0 Then
      'Do Nothing
   Else
      Dim j As Integer
      For j = 0 To 3
         If (Check1(j).Value = 1) Then
         chec = j
         getValues (j)
         vol = V_
         MsgBox "Sim Complete: Volume = " & vol
         whatsta = Str$(chec + 1)
         Set bisi(select_) = New Concent
         Load bisi(select_)
         bisi(select_).Show
         ElseIf (Check1(j).Value = 0) Then
            'Do Nothing
      End If
      Next j

   End If
   Exit Sub
      select_ = sel(month.Text)
   If select_ = 0 Then
      'Do Nothing
   Else
```

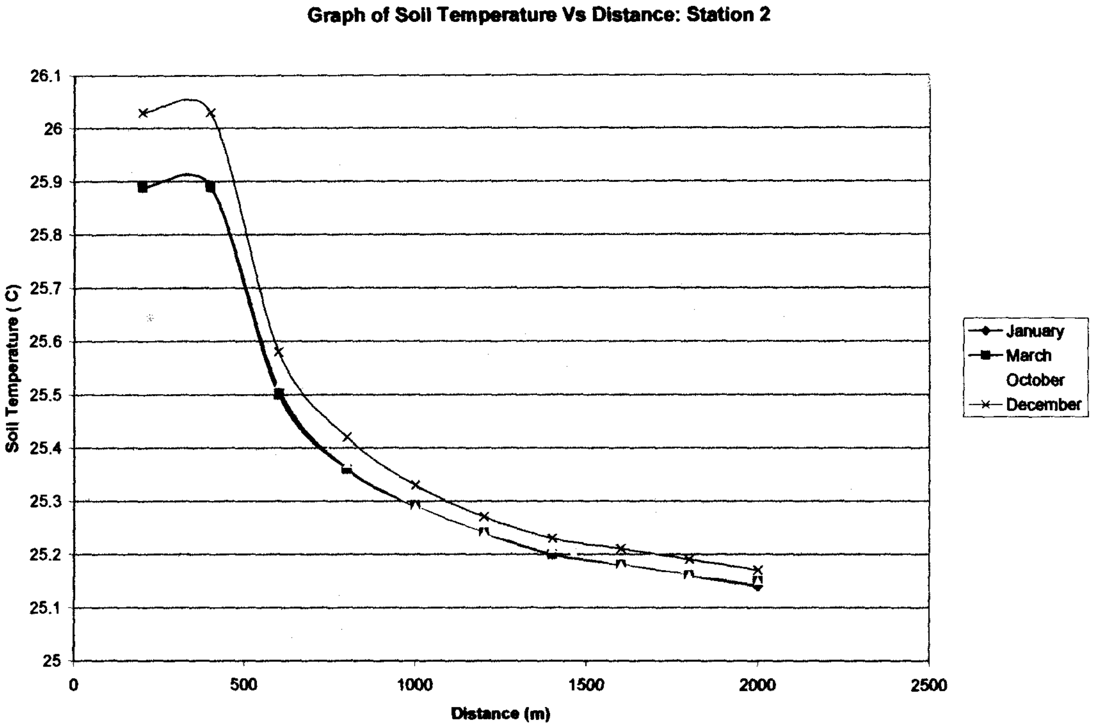
```
    End If

mineError:
    Dim response As Integer, Description As Integer
    Description = vbExclamation + vbRetryCancel
    response = MsgBox(Err.Description & ": Invalid Data!!!", Description, "Invalid Data
Error")
    If response = vbRetry Then
        Resume retry
    End If
End Sub

Private Function D() As Double
    D = Da_ * Ta_ / Ts_
End Function

Private Function Nr() As Double
    Nr = 28.951 / (D() * V_)
End Function

Private Function K1() As Double
    Dim E As Double
    Dim Qr, a, alpha As Double
    E = 75
    Qr = 0.0388
    a = 0.35
    alpha = 0.22
    K1 = (alpha * Qr ^ 2 - alpha * Qr ^ 2 * a) / (0.0027 * E ^ 2)
End Function
Private Function K2() As Double
    K2 = (r_ * Cp_ * Ta_ * (x * Cr + Da_))
End Function
Private Function K3() As Double
    K3 = 145.3 * x ^ 0.4
End Function
Private Function K4() As Double
    K4 = r_ * Cp_ * Ta_ * x
End Function
Private Function K5() As Double
    K5 = K1() ^ 0.395 * D() / K3() ^ 2.5
End Function
Private Function K6() As Double
    K6 = (K2() + r_ * D() * V_ * C_ * Ts_) / K5()
End Function
Private Function K7() As Double
    K7 = K6() ^ 0.285 / (D() * V_ * C_)
```

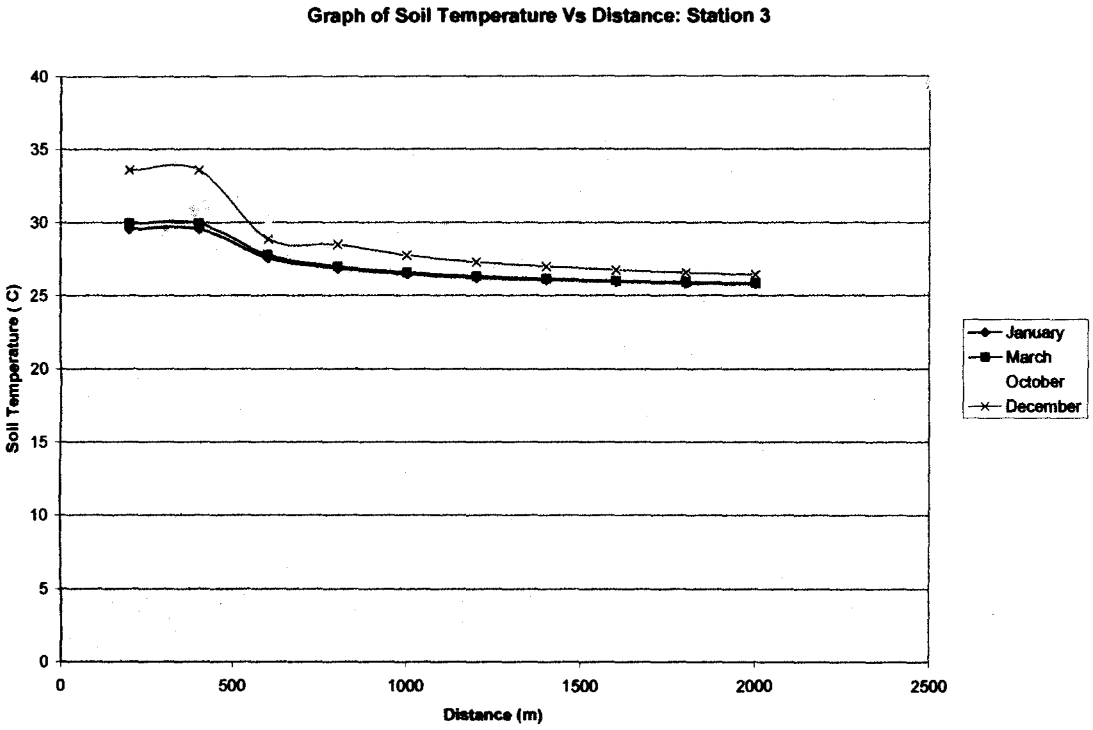
```
End Function
Private Function K8() As Double
   K8 = K5() ^ 0.255 * K7()
End Function
Private Function K9() As Double
   K9 = K8() ^ 2.3 * K4()
End Function
Private Function K10() As Double
   K10 = K9() * (K8() ^ 2.3 * D() * V_ * C_ * Ts_)
End Function
Private Function Tst() As Double
   Dim tempr As Double
   Tst = Round((K10() ^ -0.77 * Ts_ ^ 1.77 * K8() ^ 1.77 * (D * V_ * C_) ^ 0.77) *
1000, 2) -273
End Function
Private Sub Command1_Click()
   callMonth
End Sub
```

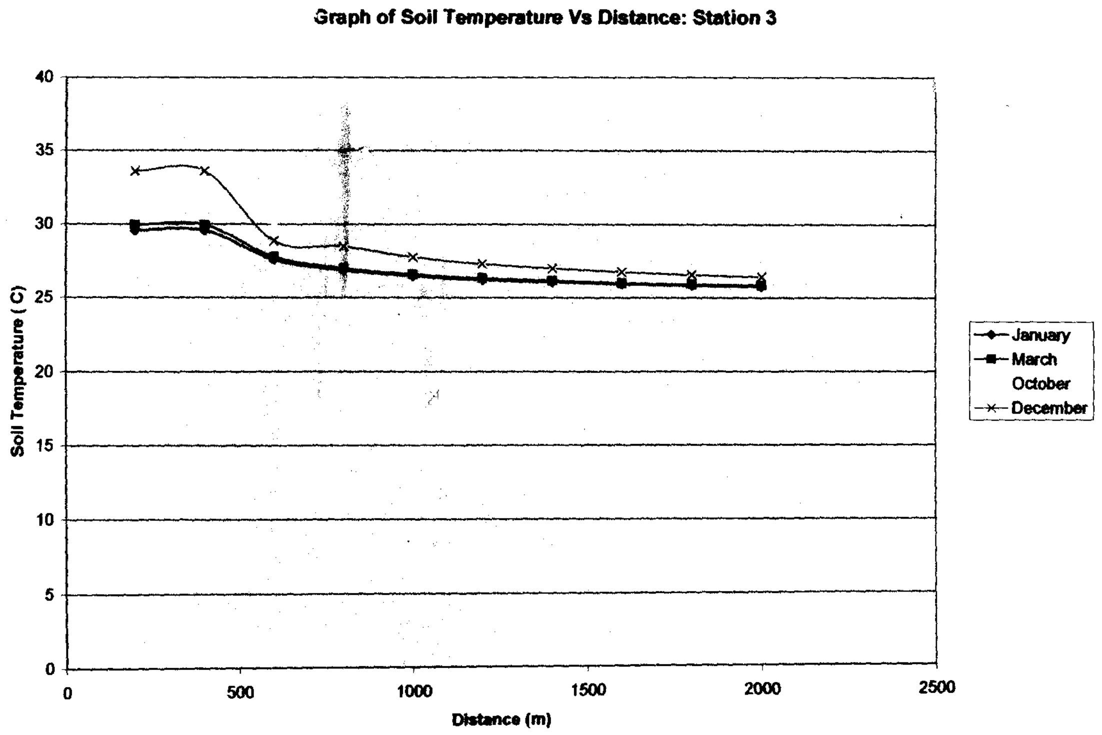
APPENDIX B

GRAPHS




Graph of Soil Temperature Vs Distance: Station 2
Soil Temperature (C)
26.1
26
25.9
25.8
25.7
25.6
25.5
25.4
25.3
25.2
25.1
25
0
500
1000
1500
2000
2500
Distance (m)
January
March
October
December


Graph of Soil Temperature Vs Distance: Station 3
Soil Temperature (C)
40
35
30
25
20
15
10
5
0
0
500
1000
1500
2000
2500
Distance (m)
January
March
October
December


Graph of Soil Temperature Vs Distance: Station 3
Soil Temperature (C)
0
5
10
15
20
25
30
35
40
Distance (m)
0
500
1000
1500
2000
2500
January
March
October
December