MODELLING AND SIMULATION OF THE DISPERSION OF HEAT RADIATED FROM GAS FLARES IN NIGER DELTA

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In partial fulfillment of the requirement for the award of Bachelor of Engineering (B. Eng) Degree in Chemical Engineering.

NOVEMBER, 2004.

DECLARATION

I, UFARUNA OJOCHENEMI ROSE with registration number 98/7103EH declare that this research project report is my original work and has not been presented elsewhere to the best of my knowledge.

[signature] 23-11-04

Ufaruna O. R. Date

CERTIFICATION

This research project report by ***Ufaruna Ojochenemi Rose*** has been examined and certified under the supervision of Engr. Abdulkareem Saka to be adequate in scope and quality for the partial fulfilment of the requirement for the award of Bachelor of Engineering (B. Engr.) in Chemical Engineering.

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Dr. F. A. Aberuagha (HEAD OF DEPARTMENT)	Date
______________________	______________________
EXTERNAL EXAMINER	Date

DEDICATION

This project is dedicated to the Lord of the Universe, the Great I Am, the Almighty God and also to my dear and wonderful parents Dr. and Mrs. Ufaruna.

ACKNOWLEDGEMENT

I give glory to God Almighty for the successful completion of my degree program. I praise Him for His faithfulness to me, may His name be gloried forever. He is the reason why I am alive today. Also I am grateful to my parents for their support throughout my undergraduate days.

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ABSTRACT

The radiant heat energy produced as a result of flaring in flow stations in Niger Delta area of Nigeria has had adverse effect on the environment especially the immediate environment within the vicinity of the flow stations and it has led to conflicts between the host communities and oil exploring companies. An evaluation of the radiant heat energy was carried out considering two stations. A mathematical model was developed and simulated using a Visual Basic program.

The simulated values shows that an increase in the volume of gas flared and increase in stack efficiency leads to a corresponding increase in the quantity of heat reflected. It was observed that the model and experimental values to a large extend conform with the simulated results.

Also heat reflected decreases with increasing distance, therefore human residential areas and farms should be located outside the unsafe zones of the flaring stations to avoid damages to human health and agricultural produce.

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CHAPTER ONE

1.0 INTRODUCTION

Nigeria like most other less developed countries in the early part of the 70s was engaged in intensive natural resource exploitation as a way of stimulating economic growth. As at 1976, about 10 years from the start of oil exploration and export, figures available from the federal of statistics stated the oil has come to account for about 14% of the nation's gross domestic product (GDP) of Nigeria, 95% of the total export and over 80% of government's annual revenue (Charles, 2003). Also total export peaked at 2 millions barrels per day of crude oil with price range 18-22 US dollars per barrel (Charles, 2003). This created more opportunity for the development of new fields and increase granting of mining licences and intensive exploration of oil mineral resources in the country.

Most of the crude oil comes from reservoir containing gas, which is produced along with the oil. This associated natural gas is separated from the oil at a flow station. However, in Nigeria, about 75% of the associated gas is flared due to the underdeveloped local market for gas in the country. The gas currently flared in estimated at two billion cubic feet per day (scf/d) or 56,600m^3, the highest in any member nation of OPEC.(SPDC, 1999).

During gas flaring, large volumes of several gases are released into the atmosphere, some of which are harmful to human health depending on their quantities in the atmosphere. Hydrocarbon and inorganic gases are the main products of incomplete combustion released into the air during gas flaring. Continuous combustion of fossil fuel i.e. coal, oil and natural gas contributes immensely to the atmospheric content of sulphur, nitrogen and carbon. Combustion of associated gas releases heat radiation into the environment (University of Ibadan, 1998). The heat radiation from gas flaring greatly affects the surrounding environment and particular crops planted within the vicinity of gas flare stations. It also has a devastating effect on microorganisms and aquatic life.

Gas flaring apart from being detrimental to the environment has been discovered to represent a monumental waste of resources. Models can be developed to estimate the quantity of heat radiation with respect to distance. Modelling is the process of translating a problem from it's real environment to a mathematical environment where it is more conveniently studied. Mathematical models are developed using mathematical concepts such as functions and equations. The application and validation of a model is called simulation.

1.1 AIMS AND OBJECTS

The aim of this project is to develop a modelling equation for the dispersion of heat radiation from gas flaring. This can be achieved via the realisation of the following objectives:

1. Develop of a mathematical model to determine the quantity of heat released by gas flaring in flow stations.
2. Collection of experimental analysis and data from the flare station to confirm the validity of the model.

3. Develop a computer package for the model and simulate the developed computer programme using Visual Basic to find the interaction between various parameters affecting heat dispersion.
4. Determine the safe distance from the flare station for farming and human settlement.

1.2 Scope of Work

This research work covers the investigation into the extent of heat radiation from gas flaring considering the effect on human, animal and the surrounding environment and also the development of a mathematical model to determine the heat radiation with respect to distance. It also includes the suggestion of control measures that can eliminate or reduce heat radiation from gas flaring to the bearest minimum.

1.3 Justification of Study

The development in science and technology, which includes chemical engineering contributes immensely to continued industrial growth and advancement. Though not much investigation into the effect of heat radiation resulting from gas flaring has been undertaken despite it's detrimental effect on the environment. This research work and the development of a mathematical model to estimate the quantity of heat energy at a particular distance will help to suggest possible means of controlling the heat energy radiated and ways of putting it into better use.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 PETROLEUM PROSPECTING

Right from time immemorial, even before the advent of British, agriculture had all along been the traditional means of livelihood of the different people occupying the tracts of land known as Nigeria. The discovery of petroleum about a quarter of a century ago has altered radically the economic pattern with petroleum playing the dominant role and agricultural products relegated to the background.

Crude oil, which means rock oil, a dark yellow or brown hydrocarbon (over 90% by weight) waxes asphalt, aromatics and resinous substances such as sulphur, nitrogen, oxygen and ash (Abdullahi, 2000). Also crude is a rich natural resource from which numerous useful substances such as gaseous and liquid fuels of all kinds, lubricants of diverse applications, drugs, chemicals of different types both for domestic and industrial uses, clothing, building materials, food packaging and household products can be obtained. Therefore, sometimes crude is referred to as "black gold".

In 1937, Shell D'Aircy petroleum company of Nigeria, the forerunner of the present Shell Development Company became the first company to acquire a concession for mineral oil prospecting in the form of oil exploration licences covering areas in and around offshore and onshore parts of Niger-Delta. Between 1938 and 1940, organised geophysical and geological reconnaissance studies were undertaken in the area (Shola, 2000). The efforts were further intensified with detailed gravimetric and seismic surveys. The first potentially commercial oil discovery was made in 1956 in Olobin near Port Harcourt in the Rivers State (Chares, 2003). Crude is usually found trapped in certain porous geological strata in some parts of the world. It is formed in the earth's crust as a result of the transformation of deposits of dead marine organisms subjected geologically to heat and pressure over a long period of time (Andy, 2003). All oil deposits contain natural gas which is formed alongside with crude and associated with the crude.

2.2 Natural Gas

Natural gas is closely related to crude. Both are formed in the earth's crust as a result of the transformation of organic matter due to heat and pressure of the overlying rock. Also the most volatile fraction obtained during the first distillation of crude oil are the gas fraction which are collected under pressure (Abdullahi, 2002). Natural gas is formed either as biogenic or as thermogenic gas.biogenic gas arises from the bacterial decay of organic matter, while thermogenic gas arises from the excessive heating of already decayed material including oil. This heating occurs at the depths at which oil is formed by thermogenic processes (Era Handbook). An example of gas hydrocarbons produced as a result of microbial decomposition of organic substances is methane, which is the major component of natural gas and a product of bacteria, an agent of decay.

Natural gas can be found either as associated or non-associated gas. Associated natural gas are gas hydrocarbons formed alongside with crude during the process of crude formation. Therefore associated gas occurs naturally in crude oil deposits. Non-associated gas deposits do not contain crude oil and is formed in three ways.

i. Where the rock or oil has been heated to above 150°C so that all the oil has been cracked to become gas i.e. where crude undergoes a thermogenic process

ii. Where the gas in crude deposits has been able to migrate through permeable rock strata on its own..

iii. Where the source rock is gas-prone i.e. where it is made up of a high percentage of gas deposits derived from plant remains (i.e. organic matter) which has gone through a biogenic process.

Natural gas is a mixture of flammable hydrocarbon vapours and gases found naturally beneath the surface of the earth, which consists majorly of aliphatic hydrocarbons i.e. methane and it's homologues. The content of homologues is not even in all oil deposits.For instance the deeper the location of the gas deposit,the higher the number of methane homologues, also in gas condensate fields, the content of methane homologues is considerably higher than the level methane and in gases associated with oil,the content of methane homologues is comparable with the content of methane. In addition to methane, natural gas sometimes contains liquid petroleum gases (LPG) such as propane, butane and pentane. Where LPG is present the gas is referred to as wet natural gas. Most of the natural gas currently produced and flared in Nigeria is associated gas. Generally, associated gas is usually wet while non-associated gas is dry i.e. low in LPG. The Nigeria natural gas can be roughly be described as (Abdulkareem, 2003)

Table 2.1

Component	Percentage Composition
Methane	47
Ethane	18
Propane	20
Butane	5
Pentane	9
Others	1

Other components commonly found in natural gas are carbon dioxide, hydrogen sulphide, nitrogen and helium. Usually they constitute an insignificant proportion of natural gas combustion. However in some locations their concentration can be considerably higher. According to an environmental impact assessment study undertaken for Nigeria Liquefied Natural Gas Project in 1995, the trace elements in Nigeria natural gas are as follows (ERA Handbook);

Table 2.2

Trace elements in Nigeria natural gas	mg/m^3
Mercury	0.015
Hydrogen sulphide	5.00
Mercaptans	2.00
Volatile sulphur	0.700
Total sulphur	30.00

Also Nigerian natural gas is lean in nitrogen (maximum 0.3%) and has a low sulphur content (minimum 30mg/m^3).

The distribution of natural gas is not even throughout the world.Two world regions, the former soviet union and the middle east have 70% of the total gas reserves. Africa's proven gas reserve has grown strong over the past 20 years and in 1995 totalled about 6.3 trillion cubic meter (tcm) with potential reserves estimated at 17.65 trillion cubic meter in the year 2010 (Shola, 2000).

Of the proven gas reserves in Africa, 78% are in Nigeria, with the rest concentrated in few other countries like Algeria, Tanzania, Mozambique, Libya, Angola and Nambia in sub-saharan African. The total natural gas reserves are estimated at 4,765 10cm and present recoverable reserves are estimated at 8790 10cm (Abdullahi, 2000). The most notable reserves are concentrated in Angola, Mozambique and Nambia. The table below shows the natural gas reserves of OPEC and non-OPEC countries as reported by the International Energy Agency (Ilori 1996, Adebayo,1999).

Table 2.3: Natural gas reserves of OPEC and non-OPEC countries

Countries	**Quantity (Billion cubic meter)**
Algeria	3,720
Gabon	12
Indonesia	3,235
Iran	20,764

Countries	Quantity (Billion cubic meter)
Iraq	3,115
Kuwait	1,493
Libya	1,300
Nigeria	3,450
Qater	7,070
Saudi Arabia	5,154
United Arab Emitate	5,777
Venezuela	3,925
Total Opec	59,025
Northern America	6,932
Latin America	7,848
Eastern Europe	58,559
Western Europe	6,292
Middle East	45,038
Africa	9,982
Asia Oceania	14,224
World Total Non-OPEC	148,875
World Total	207,900

100 million standard cubic feet = 3 million cubic meter.

2.3 NATURAL GAS AND NIGERIA

In energy terms, the quantity of natural gas in Nigeria is said to be more than twice the quantity of crude oil. It is estimated that the country's reserve production ratio is about 125 years compared to that of crude oil of less than 30 years (Shell, 2003). Nigeria has a proven reserve of 3,100 billion cubic meters, some 2% of the world reserves corresponding to a reserve of approximately 20 billion barrels of crude oil (Era Handbook, Shell-Nigeria, 2003). Therefore Nigeria is often described by petroleum experts as a natural gas province with some oil in it. This puts the country in the 10 top nations in the world in terms of natural gas reserves. As with oil, Nigerian natural gas is especially valued because of its low sulphur content (Era Handbook).

However, in Nigeria, the local market for natural gas is underdeveloped. Since the 1970's the higher level of oil production of about 2 million barrel per day as at today has resolved in the production of large quantities of associated gas for which there was no demand until recently. When the century's oil and gas industry was being conceptualised, the utilisation of the accompanied gas was not considered, therefore most of the associated gas was flared. Its utilisation is presently limited to small quantities being used for power generations, pressure maintenance in some industrial processes on a relatively modest scale, also as fuel for petroleum operations and for enhanced oil recovery projects. Also Nigeria has very few pipelines to get gas to the users and as such, due to the lack of gas utilisation infrastructure coupled with faulty method of exploration, the country flares 75% of the gas it produces and re-injects only 12% to enhance oil recovery (Shell-Nigeria, 2003).

2.4 GAS FLARING

During oil exploitation and exploration as the pressure goes down gases come to the surface of the oil and are released into the environment in volumes of 30 – 300m^3/ton of crude oil drilled. Due to the absence of the needed facilities and equipment for gas collection and processing, these associated gases are routinely flared in the course of producing and processing oil and they account for about 30% of the gross production of combustible gases in the world.

Flaring is a means of safely disposing waste gases through the use of combustion. With elevated flare the combustion is carried out through the top of a pipe or stack where the burner and igniter are located. It is a common practice in oil production process, therefore it is not necessity an ecological or social crime to flare gas. However, the Nigerian case attracts more attention given the volume of gas flared since the beginning of commercial oil production in the country. The country flares 75% of associated gas produced per annum while 25% is used as fuel gas in the field, sold to industries, used for gas lift operations or reinjected to enhance oil recovery operations. The bulk of this gas is flared in the Niger Delta. The Rivers and Delta states makes up 80% of the region and account for 75% of Nigeria's petroleum resources whereas only 0.6% is flared in USA and 4.3% in the UK.

It is estimated that about 2 billion cubic feet of gas is currently flared in Nigeria, the highest in any member nation of OPEC.In 1989 alone, Nigeria flared a reported 617 billion cubic feet of associated, releasing 30 million tons of carbondioxide in the process. The waste through gas flaring is enormous annually equalling about 45% of the energy requirements of france, the world's fourth largest economy. This flaring of large volumes of associated gas is a waste of vital natural resource and is untenable in the long term. By the end of 1988, the gas flared spanning over 300-field locations amounted to a waste in heat and energy equivalent of about 60×10^9 kW/h which is approximately equal to all the total electrical power generated by NEPA for that year (Ilori, 1996).

All combustible materials or substances require a definite proportion of oxygen for complete burning. In the case of flared natural gas and various types of gas burners, air or pure oxygen is mixed with the gas at the base of the burner so that carbon is consumed almost instantaneously at the mouth of the burner therefore such flares are non-luminous.

The burning process itself known as combustion is a rapid oxidation or burning of a substance with simultaneous evolution of heat and usually light. In the case of common fuels, the process is one of chemical combination with atmospheric oxygen to produce as the principal products, carbon dioxide, carbon monoxide and water with sulphur that may be generated by the minor constituents of the fuel as air pollutants.

The combustion process is accompanied by the production of flames, which in turn produce light. Flame on the other hand is a glowing body of mixed gases undergoing the process of combustion. Flames generally consist of a mixture of oxygen (or air) and another gas usually such combustile substances as hydrogen, carbon monoxide or hydrocarbon. The combustion of gaseous hydrocarbon contained in natural gas is an exothermic process which result in the evolution of heat in the atmosphere and endangers animal and plant life around the vicinity of gas flare.

The heat radiation from the flame is determined by the flame temperature, gas flow rate and the geometric design of the flame stack. Typical gas flares in Nigeria oil fields are located at ground level and are surrounded by thick vegetation, farmland and village huts 20 – 30 metres from the flare.

The issue of gas flaring could remain the most constraining factor for future oil growth as international and natural environmental pressures to reduce flaring cannot be ignored. By government regulations, this percentage of flared gas should be reduced to zero by the year 2008.

Table 2.4: Flaring of Natural Gas in Major Producing Countries (Percentage of Gross Production in 1991)

Country	Percentage by Volume
USA	0.6
Holland	0.0
Britain	4.3
Ex-USSR	1.5
Mexico	5.6
Nigeria	76.6
Libya	20.0
Saudi Arabia	20.0
Iran	19.0
Algeria	4.0

Source: Escravos staff appraisal report 1993

Table 2.5: Annual Oil and Gas Production and Gas Flared in Nigeria (1975 – 1999)

Year	**Crude Oil (in Barrel)**	**Gas production (m^3)**	**Gas flared (mm^3)**
1975	660148	18656	18333
1976	7580581	21276	20617
1977	766055	21924	20552
1978	696325	27618	19440
1979	845464	24885	26073
1980	760117	17202	22904
1981	525291	14830	14162
1982	470638	15207	11940
1983	450961	16251	11948
1984	507487	18426	14848
1985	547088	19900	14848
1986	535929	15580	12817
1987	482886	20212	13917
1988	529006	26300	12291
1989	626650	28163	14737
1990	660559	31587	21820
1991	689850	32465	25934
1992	711340	33445	24588
1993	691400	33928	25406

Year	Crude Oil (in Barrel)	Gas production (m^3)	Gas flared (mm^3)
1994	701370	34621	25934
1995	705435	34884	26478
1996	708644	35067	26758
1997	707897	35244	26811
1998	695454	35456	27891
1999	720561	35778	29085

Source: NNPC Lagos and Central Bank, Nigeria

2.5 IMPACT OF GAS FLARING

There is no doubt that the Nigerian oil industry has affected the country in a variety of ways at the same time. It has fashioned a remarkable economic landscape for the country but on the other hand, ever since the discovery of oil in Nigeria in the 1950s, the country has been suffering the negative environment consequences of oil development, these negative impacts precipitated by the introduction of its own unwanted by-products into the environment may be catastrophic if allowed to build-up and unattended to.

The growth of the country's oil industry, combined with a population explosion and a lack of environmental regulation has led to substantial damage to Nigeria's environment predominantly the Niger-Delta region, the centre of the country's oil industry. For example, the rampant flaring of natural gas in the Niger Delta during oil production is the main culprit making natural gas the main source of carbon emissions in Nigeria. The people in most oil communities have to live with gas stacks that flare gas 24 hours a day at a temperature of 13 – 14,000°C. In 1994, these gases flared according to World Bank Report produced 35 million tons of CO_2 and 12 million tons of methane more than the rest of the world. This makes the oil industry in Nigeria the single biggest source of global warming in the world. Therefore the impact of gas flaring in Nigeria is of local and global concern. Even in the immediate environment of these flares; amidst conflicting claims, field evidence seems to support the widespread postulation that flaring apart from human impacts has a direct relationship with acidification water, crop damage, ozone depletion, green house effect, global warming. It also causes noise, elevation of temperature, emission of volatile organic compounds and particulates, water pollution, retarded crop yield, corroded roofs and lung diseases.

2.5.1 Ozone Depletion

Ozone gas (O_3) occurs naturally in the upper atmosphere (stratosphere) 20 – 25 kilometres above earth surface. It filters out the harmful ultraviolet radiation (UV-B) and provides protective screen to earth.

Scientist in 1970 discovered that the layer was being attacked by chlorine and atoms released by the breakdown of a variety of compounds of anthropogenic origin including various chlorohydrocarbon (CFC) and halogens which are used in refrigerators, air conditioning systems, cleaning solvents and aerosol sprays. Light gives off the chlorine atom from a CFC's molecule. Chlorine atoms are not affected by interacting with ozone and as a result each of chlorine molecule given off has the ability to destroy a large amount of ozone for an extended period of time. It is believed that ozone layer depletion has accelerated since 1960s and a hole has been discovered in ozone layer. Also, it is estimated that with the currently increasing trend in pollution, the ozone layer may evade by 10% over the next 50 – 75 years. This will result in the increase in ultraviolet radiation to the earth which will eventually lead to increase in the incidence of skin cancer, reduced immunity to infectious diseases and eye diseases may increase in addition to severe changes in climate, ecosystem and agriculture. For example it affects the growth rates of oceanic plankton which is the base of all marine food chain. The chlorine already released into the atmosphere would continue to destroy the ozone layer for many decades even if CFC's uses were discontinued.

2.5.2 Global Warming (Green House Effect)

Global warming is a term used today to describe the warming of the earth's surface and lower atmosphere that tends to intensify with an increase in atmospheric carbon dioxide and other green house gases in the atmosphere. This phenomenon is the result of what is known as green house effect. The atmosphere allows a large percentage of the rays of visible light from the sun to reach the earth's surface and heat it. A part of this energy is re-radiated by the earth's surface in the form of long-wave infrared radiation, much of which is absorbed by green house gases like CO_2 and water vapour in the atmosphere, this also is partly reflected back to the earth's surface as heat. This way the atmosphere acts as a blanket keeping the warmth of the earth from escaping back into space. This is roughly analogous to the effect produced by the glass plane of a green house, which transmits sunlight in the visible range but hold in heat. The trapping of this infrared radiation causes the earth's surface and lower atmospheric layers to warm to a higher temperature than would otherwise be the case. Aside this green house heating, the earth's average temperature would be only about – 73°C (-100F), even the oceans would be frozen under such conditions.

Alternatively a "runaway" green house effect like that found on the other planet venus would result in surface temperature as high as 500°C (932°F) which are two extremes. Owing to the rise in atmospheric CO_2 caused by modern industrial societies widespread combustion of fossils (coal, oil and natural gas), the green house effect on the earth may be intensified and long term climatic changes may result. An increase in atmospheric concentrations of other trace gases such as chloroflouro carbons (freons), nitrous oxide and methane due largely to human activity may also aggravate green house conditions. A growing number of scientists have predicted that significant alterations in climate patterns will be seen by the turn of the century. They estimate that global average temperature could increase by as much as 5°C (9°F) by the middle of the 21st century. Such global warming would cause polar ice can and mountain glaciers to melt rapidly and result in appreciably higher coastal waters. The rise in global temperature would also produce new patterns and extremes of drought, rainfall seriously disrupting food production in certain regions.

The World Bank estimates that gas flaring in Niger-Delta release some 35 million tons of CO_2 annually into the air (Nane Wotor, 1998). Several other studies reported on the effect of global warming and it's possible impact on the sea level rise in West Africa. The conclusion of this analysis is that Niger-Delta is particularly sensitive to sea level rise in the region. It is estimated that at the rate of subsidence of the Niger Delta, the net rise in sea level will be showed as subsidence rate of more than 2.5cm/year. A one metre rise in sea level could flood a land area as large as 18,000 sqkm and force millions of people to relocate.

2.5.3 Impact of Heat on Soil

The soil constitutes a major storage location for heat, acting as sink for energy during the day and a source to the surface at night. It also gives support to plant life and acts as a major source of plant nutrient. The temperature of the soil also is one the most critical factors that influence important physical, chemical and biological processes that takes place in the soil for example bacteria growth and plant production are both temperature dependent. Heat from gas flares coupled with solar radiation falls on the soil and results in increase in the soil temperature. Increase in soil heat content has it's advantage and disadvantage.Icreased heat on the soil reduces the diseases of fruits and Vegetables and the incidence of insects generally but on other hand, increase in soil temperature determines some plant species that can be found in the surrounding. Some plant species like potatoes cannot survive in a soil of high temperature.

2.5.4 Impact of Heat on Water and Aquatic Life

Light is very important in the life cycle of plants and animals but the artificial situation whereby bright light shines continuously day and night for many years has its own adverse effects. Local fishermen complained that certain species of shrimps that were caught in the past during the nights no longer existed. It was inferred that the continuous bright light from the flares probably disturbed their mating habit. Also the fire generates constant heat which in turn evaporates water produced around the flare pit thus increasing the salinity of the pool water.

2.5.4.1 Acid Rain

Rain water is another receptor for gaseous emissions from flaring and is responsible for distribution of the wet deposition of acidifying elements.

Clean or unpolluted rain has a slightly acidic pH of 5.6. The extra acidity in rain comes from the reaction of air pollutants primarily sulphur oxides, nitrogen oxides and carbon dioxide in the air. When carbon dioxide reacts with water, it forms carbonic acid which is a weak acid.

$CO_2 + H_2O \rightarrow HCO_3$

Therefore acid rain is a fall out from industrial and vehicular pollutants particularly oxides of sulphur and nitrogen. Acid rain produces several negative effects on the world in which we live. It damages buildings, forests, crops and plants and acidifies surface water resources.

2.6 MATHEMATICAL MODELLING AND SIMULATION

2.6.1 Mathematical Modelling

Modelling can be defined as the process of translating a problem from its real environmental to a mathematical environment in which it is more conveniently studied. A model is a mathematical abstraction of a real process. It represents the mathematical aspect of system or process of interest including both the physical and chemical phenomena taking place there in mathematical models are created in order to enhance our ability to understand, predict and control the possible behaviour of the system. It also provides the simplest possible descriptions of a system which is an exact scaled down replica of the prototype, at the same time retaining its physical character as a result of retaining the physical properties of a system (William, 1990).

Mathematical models are created using mathematical concepts such as functions and equations which have fundamental physical and chemical laws such as the law of energy momentum conservation stated in their time derivatives form as its basis. Other parameters are either obtained from process operating data bank or are obtained experimentally. While modelling there is need to make reasonable and simple assumptions about the system. Many different models can be developed for tackling the same problem. The outcome of the model is dependent on the assumption because they impose limitation on the model. Some models may be better than others in that they are useful or more accurate. These assumptions must be carefully considered when evaluating results.

In order to obtain a solution, the numbers of variable must equal the number of equation i.e. the degree of freedom must be zero (Willam, 1990). Therefore care must be taken not to under specify or over specify the number of variables or equations describing the system. Generally the success of a model depends on how easily it can be used and how accurate its predictions are. Any model has a limited range of validity and it cannot be applied outside this range.

2.6.2 Simulation

Simulation is the implementation and validation of a model. It is the application of modelling techniques to real system which enable information on the system to be gained without either constructing or operating the full-scale system under consideration.

They are two types of simulation methods: Digital and analogue simulation. Digital simulation which involve the use of code and programme are more in use since they can be implemented on modern computer with exceptional speed and accuracy. Simulation is used for two principal reasons:

1. To provide a convenient, inexpensive and time saving means of gaining understanding and insight under a variety of operating conditions.
2. To give greater understanding and insight into the behaviour of the physical system and the principle upon which its design is based.

CHAPTER THREE

3.0 RESEARCH METHODOLOGY

Parameters such as the volume of gas flared, density of flared gas etc. were measured in the course of this research work in order to obtain data for the model.

3.1 DETERMINATION OF HEAT RADIATION FROM FLARE

Radiometer was used to measure the intensity of radiation from the flare site. The radiometer was placed at the required distance from the flare point. This distance was measured using measuring tape and was recorded.

The optical system of the equipment was adjusted to ensure that the radiation from the target fell on the deflecting element and only radiation of the required wavelength range was detected. The radiant energy received by the detecting element in the equipment was converted to electrical energy, which was displayed by the recorder or indicator. This procedure was carried out for various distances from the flare point and the result was recorded on a daily basis,and evaluated on a monthly basis.

CHAPTER FOUR

4.0 MATHEMATICAL MODELLING OF HEAT RADIATION FROM GAS FLARING

4.1 ASSUMPTIONS

The following assumptions were made in order to develop the mathematical model for the heat radiation from gas flaring:

i. The area is assumed to be a bed of soil i.e. of constant heat capacity.

ii. The intensity of the sun is uniform for a given area at a given time

iii. Heats from flares are used in vapourising water, retained by the soil and the remaining reflected back

iv. Combustion is incomplete in air

v. The area is a tropical forest

Below is the schematic diagram of heat radiation in a flare station.

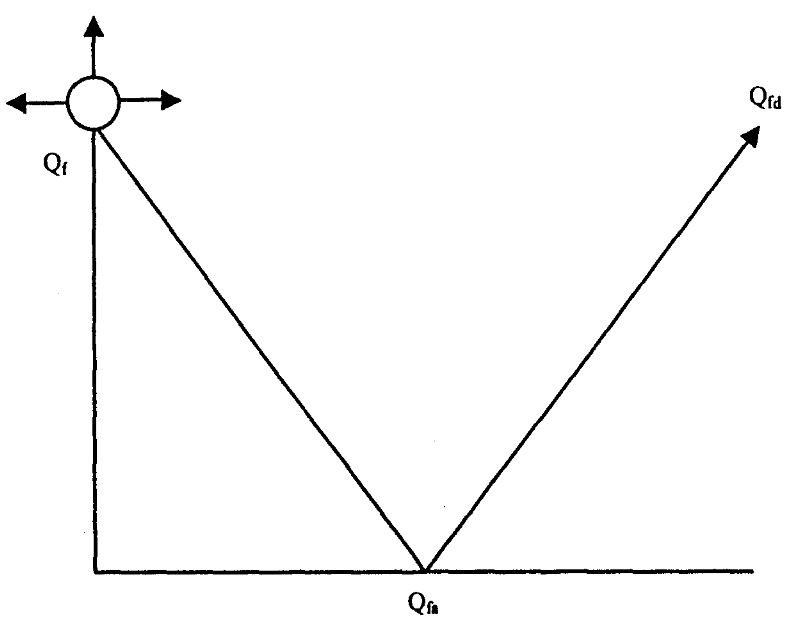

Figure 4.1

4.2 HEAT BALANCE

Taking heat balance from figure 4.1,

$Q_f = Q_{fd} + Q_{fa}$ ....(1)

Where

Q_f = heat from flare gases

Q_{fa} = heat absorbed by earth from flare gas

Q_{fd} = heat from flare reflected

From the assumptions made

$Q_{fa} = Q_s + Q_v$ ....(2)

Where

Q_s = heat retained by soil

Q_v = heat used in vapoursing water

Substituting equation (2) into (1) gives

$Q_f = Q_{fd} + Q_s + Q_v$ ....(3)

Rearranging the variables to make Q_{fd} the subject of the formula gives

$Q_{fd} = Q_f - Q_s - Q_v$ ....(4)

Where

$Q_s = M_s C_s \int_{T_{soil}}^{T_s} dT$ ....(5)

From equation (5)

$Q_s = M_s C_s [T_s - T_{soil}]$ ....(5b)

Where

M_s = mass of soil

C_s = specific heat capacity of soil

T_s = temperature of flare gas

T_{soil} = temperature of soil

$$Q_s = M_w C_w \int_{T_{soil}}^{T_s} dT + M_w \lambda_v \quad \text{.......(6a)}$$

From equation (6a)

$$Q_v = M_w C_w [T_s - T_{soil}] + M_w \lambda_v \quad \text{.......(6b)}$$

Where

M_w = mass of water

C_w = specific heat capacity of water

λ_v = latent heat of vapourisation of water

According to Albedo, a fraction of the heat radiated from the source strikes the receiving surface. (Andy, 2003). Therefore,

$$Q_c = \alpha Q_f (l - a) \quad \text{.......(8)}$$

Where

α = absorptive factor which varies with distance

a = Alhedo constant

Q_c = fraction of the heat which strikes the receiving surface

Which implies that

$$\alpha Q_f (l - a) = M_w C_w (T_s - T_{soil}) + M_w \lambda_v + M_s C_s [T_s - T_{soil}] \quad \text{.......(9)}$$

Substituting equations (9), (5b) and (6b) into equation (4) gives

$$Q_{fd} = Q_f - [M_s C_s [T_s - T_{soil}] + M_w C_w [T_s - T_{soil}] + M_w \lambda_v]$$

Which can also be written as

$$Q_{fd} = Q_f - [M_sC_s[T_s - T_{soil}] + [M_wC_w[T_s - T_{soil}] + M_w\lambda_v] \quad \text{......(10)}$$

Substituting equation (9) into (10) gives

$$Q_{fd} = Q_f - \alpha Q_f(1 - a)$$

Factorising out Q_f gives

$$Q_{fd} = Q_f(1 - \alpha(1 - a)) \quad \text{......(11)}$$

For Q_f:

According to API publications with the assumption that the flame is titled at 45°, we have

$$h_{fv} = L(\sin 45^o) = 0.707L \quad \text{......(12)}$$

Where h_{fv} is the vertical height vector of a flare stack

And L is the flame length

From (12)

$$L = h_f \times \frac{h_{fv}}{0.707} \quad \text{......(13)}$$

Also, $h_{fv} = 0.0042Q_f^{0.478}$ ......(14)

Substituting (14) into (13) gives

$$L = \frac{0.0042}{0.707}Q_f 0.478 \quad \text{......(15a)}$$

$$\therefore L = 0.00594Q_f^{0.478} \quad \text{......(15b)}$$

Also from Steward's correlating equation

$$L = 0.8632Q_f^{0.4}N' \quad \text{......(16)}$$

Where,

$$N' = \text{a combustion parameter} = \frac{\left(\dfrac{r + WP_a}{\rho}\right)^{0.4}}{[(NHV)^{0.4}(1-w)]} \quad \text{...(17)}$$

$$\text{Where } w = \text{combustion parameter} = \frac{rC_pT_a}{(rC_pT_a + NHV)}$$

NHV = flared gas net heating value, Btu/lb

r = stiochiometric air fuel ratio of flared gas

T_a = air temperature

ρ_a = ambient air density

ρ = fuel density

Equating (15b) and (16) gives

$$0.00594Q_f^{\,0.478} = 0.8632Q_f^{\,0.4}\,N' \quad \text{...(19a)}$$

From (19)

$$\frac{Q_f^{0.478}}{Q_f^{0.4}} = \frac{0.8632}{0.00594}N'$$

$$\Rightarrow Q_f^{\,0.478} \times Q_f^{\,-0.4} = 145.32N'$$

$$\Rightarrow Q_f^{\,0.478-0.4} = 145.32N'$$

$$\Rightarrow Q_f^{\,0.078} = 145.32N' \quad \text{...(19b)}$$

Substituting (18) into (17) gives

$$N' = \frac{\left(\dfrac{r + \left(\dfrac{rC_pT_a\rho_a}{rC_pT_a + NHV}\right)}{\rho}\right)^{0.4}}{(NHV)^{0.4}\left(1 - \dfrac{rC_pT_a}{rC_pT_a + NHV}\right)} \quad \text{...(20a)}$$

$$N' = \frac{\left(r + \frac{rC_pT_a\rho_a}{(rC_pT_a + NHV)\rho}\right)^{0.4}}{(NHV)^{0.4}\left(\frac{rC_pT_a + NHV - rC_pT_a}{rC_pT_a + NHV}\right)} \quad \text{.........(20b)}$$

$$N' = \frac{\left(\frac{r(rC_pT_a + NHV)\rho + rC_pT_a\rho_a}{(rC_pT_a + NHV)\rho}\right)^{0.4}}{(NHV)^{0.4}\left(\frac{NHV}{rC_pT_a + NHV}\right)} \quad \text{.........(20c)}$$

Expanding

$$N' = \frac{\frac{(r^2\rho C_pT_a + r\rho NHV + rC_pT_a\rho_a)^{0.4}}{(rC_pT_a + NHV)^{0.4}\rho^{0.4}}}{\frac{(NHV)^{1+0.4}}{(rC_pT_a + NHV)}} \quad \text{.........(20d)}$$

$$N' = \frac{\frac{(r^2\rho C_pT_a + rC_pT_a\rho_a + r\rho NHV)^{0.4}}{(rC_pT_a + NHV)^{0.4}\rho^{0.4}}}{\frac{(NHV)^{1+0.4}}{(rC_pT_a + NHV)}} \quad \text{.........(20e)}$$

$$N' = \frac{(rC_pr_a(r\rho + \rho_a) + r\rho NHV)^{0.4}}{(rC_pT_a + NHV)^{0.4}\rho^{0.4}} \times \frac{(rC_pT_a + NHV)}{(NHV)^{1.4}} \quad \text{.........(20f)}$$

$$N' = \frac{(rC_pT_a(r\rho + r_a) + r\rho NHV)^{0.4}}{\rho^{0.4}} \times \frac{(rC_pT_a + NHV)}{(NHV)^{1.4}} \times (rC_pT_a + NHV)^{-0.4} \quad \text{.........(20g)}$$

$$N' = \left(\frac{(rC_pT_a(r\rho + \rho_a) + r\rho NHV)^{0.4}}{\rho^{0.4}(NHV)^{1.4}}\right)(rC_pT_a + NHV)^{1-0.4} \quad \text{.........(20h)}$$

$$N' = \left(\frac{(rC_pT_a(r\rho + \rho_a) + r\rho NHV)^{0.4}}{\rho^{0.4}(NHV)^{1.4}}\right)(rC_pT_a + NHV)^{0.6} \quad \text{.........(20k)}$$

Substituting (20k) into (19b) gives

$$Q_f^{\,0.078} = 145.32\left(\frac{(rC_pT_a(r\rho + \rho_a) + r\rho NHV)^{0.4}}{\rho^{0.4}(NHV)^{1.4}}\right)(rC_pT_a + NHV)^{0.6} \quad \text{.........(21)}$$

From (21)

$$Q_f = \sqrt[0.078]{145.32\left(\frac{(rC_pT_a(r\rho+\rho_a)+r\rho NHV)^{0.4}}{\rho^{0.4}(NHV)^{1.4}}\right)(rC_pT_a+NHV)^{0.6}} \quad \text{.......................(22)}$$

Substituting (12) into (21) gives

$$Q_{fd} = \left(\sqrt[0.078]{145.32\left(\frac{(rC_pT_a(r\rho+\rho_a)+r\rho NHV)^{0.4}}{\rho^{0.4}(NHV)^{1.4}}\right)(rC_pT_a+NHV)^{0.6}}\right)(1-\alpha(1-a)) \quad \text{......(23)}$$

But

$$NHV = \frac{mc\theta}{x} \quad \text{..(24)}$$

Where m= mass of flared gas

c = heat capacity of flared gas

θ = temperature of flared gas

x = distance

Substituting (24) into (23)

$$Q_{fd} = \left(\sqrt[0.078]{145.32\left(\frac{\left(rC_pT_a(r\rho+\rho_a)+r\rho\frac{mc\theta}{x}\right)^{0.4}}{\rho^{0.4}\left(\frac{mc\theta}{x}\right)^{1.4}}\right)\left(rC_pT_a+\frac{mc\theta}{x}\right)^{0.6}}\right)(1-\alpha(1-a))$$

$$Q_{fd} = \left(\sqrt[0.078]{145.32\left(\frac{\frac{(rC_pT_ax(r\rho+\rho_a)+\rho mc\theta)^{0.4}}{x^{0.4}}}{\frac{\rho^{0.4}(mc\theta)^{1.4}}{x^{1.4}}}\right)\left(\frac{rC_pT_a+mc\theta}{x}\right)^{0.6}}\right)(1-\alpha(1-a))$$

$$Q_{fd} = \left(\sqrt[0.078]{145.32\left(\frac{(rC_pT_ax(r\rho+\rho_a)+\rho mc\theta)^{0.4}}{\rho^{0.4}(mc\theta)^{1.4}}\right)(rC_pT_a+mc\theta)^{0.6}\left(\frac{x^{1.4}}{x^{0.6}x^{0.4}}\right)}\right)(1-\alpha(1-a))$$

$$Q_{fd} = \left(\sqrt[0.078]{145.32 \left(\frac{\left(rC_pT_a x(r\rho + \rho_a) + \rho mc\theta\right)^{0.4}}{\rho^{0.4}(mc\theta)^{1.4}} \right) (rC_pT_a + mc\theta)^{0.6} x^{1.4-0.6-0.4}} \right) (1 - \alpha(1 - a))$$

$$Q_{fd} = \left(\sqrt[0.078]{145.32 \left(\frac{\left(rC_pT_a x(r\rho + \rho_a) + \rho mc\theta\right)^{0.4}}{\rho^{0.4}(mc\theta)^{1.4}} \right) (rC_pT_a + mc\theta)^{0.6} x^{0.4}} \right) (1 - \alpha(1 - a)) \quad \text{.....(25)}$$

But $m = \rho_T V_T$ ....(26)

Where m = mass of flared gas

V = volume of flared gas

ρ_T = density of gas produced by gas flaring

V_T = volume of gas produced by gas flaring which can be calculated as follows:

Table 4.1: Component of gas flared

Table 4.1

Component of gas flared	**Percentage of Composition**
CH_4	47
C_2H_4	18
C_3H_8	20
C_4H_{10}	5
C_5H_{12}	9
H_2S	0.03
N_2	0.022
Others	0.068

Shown above is the composition of associated gas in crude oil (Abdulkereem, 2002).

Assuming combustion is incomplete in air, the following reactions take place during the process of combustion.

$2CH_4 + \frac{7}{2}O_2 \rightarrow CO_2 + CO + 4H_2O$ ....(27)

$C_2H_6 + 3O_2 \rightarrow CO_2 + CO + 3H_2O$ ....(28)

$C_3H_8 + 4O_2 \rightarrow CO_2 + 2CO + 4H_2O$ ....(29)

$C_4H_{10} + 5O_2 \rightarrow CO_2 + 3CO + 5H_2O$ ....(30)

$C_5H_{12} + \frac{13}{2}O_2 \rightarrow 2CO_2 + 3CO + 6H_2O$ ....(31)

$H_2S + O_2 \rightarrow SO_2 + H_2$ ....(32)

$N_2 + 2O_2 \rightarrow 2NO_2$ ....(33)

Basis: $1m^3$ of flared gas

Let S_E = stack energy

4.2.2 Calculation of the Total Volume of CO_2 Produced by Gas Flaring

FOR CO_2 FROM METHANE (CH_4)

From table 4.1, CH_4 = 47%

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

i.e. $0.47m^3$ of CH_4 was flared.

But

$\frac{S_E}{100} \times 0.47m^3 = 0.0047S_E m^3$ was used up in the combustion process ......(34a)

From (27)

2 moles of CH_4 produced 1 mole of CO_2 therefore, $0.0047S_Em^3$ of CH_4 will produce

$$\frac{0.0047S_E \times 1}{2} = 0.00235S_Em^3 \quad \text{.......(34b)}$$

FOR CO_2 FROM ETHANE (C_2H_6)

From table 4.1, $C_2H_6 = 18\%$

$$\frac{18}{100} \times 1m^3 = 0.18m^3$$

i.e. $0.18m^3$ of C_2H_6 was flared.

But

$$\frac{S_E}{100} \times 0.18m^3 = 0.0018S_Em^3 \text{ was used up in the combustion process ......(35a)}$$

From (28)

2 moles of C_2H_6 produced 1 mole of CO_2 therefore, $0.0018S_Em^3$ of C_2H_6 will produce $0.0018S_Em^3$ i.e. CO_2 from $C_2H_6 = 0.0018S_Em^3$ ....(35b)

FOR CO_2 FROM PROPANE (C_3H_8)

From table 4.1, $C_3H_8 = 20\%$

$$\frac{20}{100} \times 1m^3 = 0.2m^3$$

i.e. $0.18m^3$ of C_3H_8 was flared.

i.e. $0.2m^3$ of C_3H_8 was used up in the process ....(36a)

From (29)

1 mole of C_3H_8 produced 1 mole of CO_2, therefore $0.002S_Em^3$ will produce $0.002S_Em^3$

$\therefore$ CO_2 from $C_3H_8 = 0.002S_Em^3$ ....(36b)

FOR CO_2 FROM BUTANE (C_4H_{10})

From table 4.1, $C_4H_{10} = 5\%$

$\frac{5}{100} \times 1m^3 = 0.05m^3$, i.e. $0.05m^3$ of C_4H_{10} was flared

But $\frac{S_E}{100} \times 0.05m^3 = 0.0005S_Em^3$ of C_4H_{10} was used up in the process ....(37a)

From (30)

1 mole of C_4H_{10} produced 1 mole of CO_2, therefore $0.0005S_Em^3$ of C_4H_{10} will produce $0.0005S_Em^3$ of CO_2

$\therefore$ CO_2 from $C_4H_{10} = 0.0005S_Em^3$ ....(37b)

FOR CO_2 FROM PENTANE (C_5H_{12})

From table 4.1, $C_5H_{12} = 9\%$

$\frac{9}{100} \times 1m^3 = 0.09m^3$, i.e. $0.09m^3$ of C_5H_{12} was flared

But

$\frac{S_E}{100} \times 0.09m^3 = 0.0009S_Em^3$ of C_5H_{12} was used up in the process ....(38a)

From (31)

1 mole of C_5H_{12} produced 1 mole of CO_2, therefore $0.0009S_Em^3$ will produce $0.0009S_Em^3$ of CO_2

$\therefore$ CO_2 from $C_5H_{12} = 0.0009S_Em^3$ ....(38b)

The total volume of CO_2 generated

$$= 0.00235S_Em^3 + 0.0018S_Em^3 + 0.0025S_Em^3 + 0.0005S_Em^3 + 0.0009S_Em^3$$

$$= 0.00845S_Em^3$$

4.2.3 Calculation of the Total Volume of CO Generated

FOR CO FROM METHANE (CH_4)

From (34a), the volume of CH_4 used up in the combustion process = $0.0047S_Em^3$

Also from (27)

2 moles of CH_4 produced 1 mole of CO, therefore $0.0047S_Em^3$ of CH_4 will produce $0.00235S_Em^3$ of CO. i.e. CO from CH_4 = $0.00235S_Em^3$ ....(39)

FOR CO FROM ETHANE (C_2H_6)

From (35a), the volume of C_2H_6 used up in the combustion process = $0.0018S_Em^3$

Also from (28)

1 mole of C_2H_6 produced 1 mole of CO, therefore $0.0018S_Em^3$ of C_2H_6 will produce $0.0018S_Em^3$ of CO i.e. CO from C_2H_6 = $0.0018S_Em^3$ ....(40)

FOR CO FROM PROPANE (C_3H_8)

From (36a), the volume of C_3H_8 used up in the combustion process = $0.002S_Em^3$

Also from (29)

1 mole of C_3H_8 produced 2 moles of CO, therefore $0.002S_Em^3$ of C_3H_8 will produce

$0.002S_E$ x 2 = $0.004S_Em^3$ of CO

i.e. CO from C_3H_8 = $0.004S_E{}^{m3}$ ....(41)

FOR CO FROM BUTANE (C_4H_{10})

From (37a), the volume of butane used up = $0.005S_Em^3$

Also from (30)

1 mole of C_4H_{10} produced 3 moles of CO therefore $0.0005S_Em^3$ of C_4H_{10} will produce

$0.0005 \times 3 = 0.0015S_Em^3$ of CO

i.e. CO from $C_4H_{10} = 0.0015S_Em^3$ ....(42)

FOR CO FROM PENTANE (C_5H_{12})

From (38a), the volume of C_5H_{12} used up = $0.0009S_Em^3$

Also, from (31)

1 mole of C_5H_{12} produced 3 moles of 10 therefore $0.0009S_Em^3$ of C_5H_{12} will produce

$0.0009 \times 3 = 0.0027S_Em^3$ of CO

i.e. 10 from $C_5H_{12} = 0.0027S_Em^3$ ....(43)

The total volume of CO generated

$= 0.00235S_E + 0.0018S_E + 0.004S_E + 0.0015S_E + 0.0027S_E$

$= 0.01235S_Em^3$ ....(44)

4.2.4 Calculation of the Volume of SO_2 Generated

From table 4.1, $H_2S = 0.03\%$

Therefore, $\frac{0.03}{100} \times 1m^3 = 0.0003m^3$ of H_2S was supplied to the flare

But $\frac{S_E}{100} \times 1m^3 = 0.000003S_Em^3$ was used up from (32), 1 mole of H_2S produced 1 mole of SO_2 therefore SO_2 produced from $1m^3$ of flared gas = $3 \times 10^{-6}S_Em^3$ ....(45)

4.2.5 Calculation of the Volume of NO_2 Generated

From table 4.1, $N_2 = 0.022\%$

Therefore, $\frac{0.022}{100} \times 1m^3 = 0.00022$ of N_2 was supplied to the flare

But $\frac{S_E}{100} \times 0.00022S_E m^3$ of N_2 was used up

2 moles of NO_2 was produced by flaring 1 mole of N_2, therefore N_2 produced from $1m^3$ of flare gas $= 0.00022S_E \times 2 = 0.00044S_E m^3 = 4.4 \times 10^{-6} S_E m^3$

i.e. $4.4 \times 10^{-6} S_E m^3$ of NO_2 from $1m^3$ of flared gas ....(46)

4.2.5 Calculation of Total Un-combusted Hydrocarbon

The un-combusted fraction of the hydrocarbon (i.e. CH_4, C_3H_8, C_4H_{10} and C_5H_{12}) flared in the total hydrocarbon (THC) calculated below

$$CH_4 = (0.47 - 0.00470S_E)m^3$$

$$C_2H_6 = (0.18 - 0.0018S_E)m^3$$

$$C_3H_8 = (0.2 - 0.002S_E)m^3$$

$$C_4H_{10} = (0.05 - 0.0005S_E)m^3$$

$$C_5H_{12} = (0.09 - 0.0009S_E)m^3$$

Which implies that total hydrocarbon (THC)

$= (0.47 - 0.00470S_E) + (0.18 - 0.0018S_E) + (0.2 - 0.002S_E) + (0.05 - 0.0005S_E)$

$+ (0.09 - 0.0009S_E) = (0.99 - 0.0099S_E)m^3$ ....(47)

Therefore the total volume of gas produced by flaring $1m^3$ of gas

= volume of CO_2 + volume of CO + volume of NO_2 + volume of SO_2

+ volume of THC

$= 0.00845S_E + 0.1235S_E + 0.000003S_E + 0.00004S_E + 0.99 - 0.00990S_E$

$$= (0.99 + 0.0109074S_E)m^3 = V_T \quad \text{.....(48)}$$

Equation (48) represents the total volume of gas produced by flaring $1m^3$ of gas. But when Vm^3 of gas is flared equation (48) becomes

$$(0.99 + 0.0109074S_E)Vm^3 = V_T \quad \text{.....(49)}$$

From (26)

$$m = \rho_T V_T$$

Substituting (49) into (26) gives

$$m = \rho_T(0.99 + 0.0109074S_E)V \quad \text{.....(50)}$$

Substituting (50) into (25) gives

$$Q_{fd} = \sqrt[0.078]{145.32\left(\frac{[rC_pT_a x(r\rho + \rho_a) + \rho\rho_T(0.99 + 0.0109074S_E)VC\theta]^{0.4}}{\rho^{0.4}(\rho_T(0.99 + 0.0109074S_E)VC\theta)^{1.4}}(rxC_pT_a + \rho_T(0.99 + 0.0109074S_E)VC\theta)^{0.6}x^{0.4}\right)} \cdot (1 - \alpha(1 - a)) \quad \text{.....(51)}$$

Where $\theta = T_s - T_a$

$$\rho = \frac{\rho_a T_a}{T_s}$$

Equation (51) is the model equation for the heat reflected due to gas flaring.

CHAPTER FIVE

5.0 RESULTS AND DISCUSSION OF RESULT

5.1 RESULTS

The Results are shown in table 5.1 to 5.7.

TABLE 5.1 Experimental Data On Heat radiation Station 1

Months	Jan	Feb	Mar	Apr	May	Jun	Sep	Dec
Distance(m)	Qfd(kw/m2)	Qfd(kw/m2)	Qfd(kw/m2)	Qfd(kw/m2)	Qfd(kw/m2)	Qfd(kw/m2)	Qfd(kw/m2)	Qfd(kw/m2)
100	0.0008048	0.000553	0.00005	0.003016	0.002672	0.002735	0.001527	0.000837
150	0.0007613	0.000514	0.000076	0.002465	0.002429	0.001994	0.001668	0.000725
200	0.0006199	0.004404	0.000075	0.00101	0.003034	0.001697	0.002708	0.00062
250	0.0003298	0.000322	0.000075	0.003916	0.002175	0.001682	0.002262	0.000522
300	0.000319	0.000373	0.000094	0.000312	0.001675	0.00152	0.001929	0.000457
500	0.0000558	0.000237	0.000091	0.000979	0.001262	0.001519	0.001849	0.000305

Table 5.2: Simulation Results For Heat Radiation In Aghigho Station For Year 2000. Stack Efficiency Of 64%

Month	January	Febuary	March	April	May	June	July	August	September	October	November	December
Vol.(m3/s)	1.13E-02	1.05E-02	2.66E-04	4.05E-02	5.11E-02	2.76E-01	1.67E-01	2.18E-01	2.76E-02	1.15E-01	1.53E-01	2.70E-01
Distance (m)	Qfd(kW/m2)	Qfd(kW/m2)	Qfd(kW/m2)	Qfd(kW/m2)	Qfd(kW/m2)	Qfd(kW/m2)	Qfd(kW/m2)	Qfd(kW/m2)	Qfd(kW/m2)	Qfd(kW/m	Qfd(kW/m2)	Qfd(kW/m2)
25	0.000675	0.000584	1.84E-05	0.002441	0.002623	0.018858	0.010747	0.013846	0.001529	0.007044	0.008513	0.014958
50	0.000675	0.000584	1.84E-05	0.002441	0.002623	0.018858	0.010747	0.013846	0.001529	0.007044	0.008513	0.014958
75	0.000675	0.000584	1.84E-05	0.002441	0.002623	0.018858	0.010747	0.013846	0.001529	0.007044	0.008513	0.014958
100	0.000675	0.000584	1.84E-05	0.002441	0.002623	0.018858	0.010747	0.013846	0.001529	0.007044	0.008513	0.014958
125	0.000611	0.000529	1.66E-05	0.002209	0.002373	0.01706	0.009723	0.012526	0.001383	0.006372	0.007702	0.013532
150	0.000611	0.000529	1.66E-05	0.002209	0.002373	0.01706	0.009723	0.012526	0.001383	0.006372	0.007702	0.013532
175	0.000611	0.000529	1.66E-05	0.002209	0.002373	0.01706	0.009723	0.012526	0.001383	0.006372	0.007702	0.013532
200	0.000611	0.000529	1.66E-05	0.002209	0.002373	0.01706	0.009723	0.012526	0.001383	0.006372	0.007702	0.013532
225	0.000546	0.000473	1.49E-05	0.001976	0.002123	0.015263	0.008699	0.011207	0.001237	0.005701	0.006891	0.012107
250	0.000546	0.000473	1.49E-05	0.001976	0.002123	0.015263	0.008699	0.011207	0.001237	0.005701	0.006891	0.012107
275	0.000546	0.000473	1.49E-05	0.001976	0.002123	0.015263	0.008699	0.011207	0.001237	0.005701	0.006891	0.012107
300	0.000546	0.000473	1.49E-05	0.001976	0.002123	0.015263	0.008699	0.011207	0.001237	0.005701	0.006891	0.012107
500	0.00045	0.000389	1.22E-05	0.001627	0.001748	0.012567	0.007162	0.009227	0.001019	0.004694	0.005673	0.009968
700	0.000321	0.000278	8.74E-06	0.001162	0.001248	0.008973	0.005114	0.006588	0.000727	0.003352	0.004051	0.007117
900	0.00016	0.000139	4.36E-06	0.00058	0.000623	0.00448	0.002553	0.003289	0.000363	0.001673	0.002022	0.003554
1100	0.00016	0.000139	4.36E-06	0.00058	0.000623	0.00448	0.002553	0.003289	0.000363	0.001673	0.002022	0.003554
1300	0.00016	0.000139	4.36E-06	0.00058	0.000623	0.00448	0.002553	0.003289	0.000363	0.001673	0.002022	0.003554
1500	0.00016	0.000139	4.36E-06	0.00058	0.000623	0.00448	0.002553	0.003289	0.000363	0.001673	0.002022	0.003554

Table 5.3: Simulation Results For Heat Radiation In Aghigho Station For Year 2000. Stack Efficiency Of 74%

Month	January	Febuary	March	April	May	June	July	August	September	October	November	December
Vol. (m3/s)	1.13E-02	1.05E-02	2.66E-04	4.05E-02	5.11E-02	2.76E-01	1.67E-01	2.18E-01	2.76E-01	1.15E-01	1.53E-01	2.70E-01
Distance (m)	Qfd(kW/m2)	Qfd(kW/m2)	Qfd(kW/m2)	Qfd(kW/m2)	Qfd(kW/m2)	Qfd(kW/m2)	Qfd(kW/m2)	Qfd(kW/m2)	Qfd(kW/m2)	Qfd(kW/m2)	Qfd(kW/m2)	Qfd(kW/m2)
25	0.000718	0.000622	1.95E-05	0.002597	0.00279	0.020062	0.011434	0.01473	0.001626	0.007494	0.009057	0.015914
50	0.000718	0.000622	1.95E-05	0.002597	0.00279	0.020062	0.011434	0.01473	0.001626	0.007494	0.009057	0.015914
75	0.000718	0.000622	1.95E-05	0.002597	0.00279	0.020062	0.011434	0.01473	0.001626	0.007494	0.009057	0.015914
100	0.000718	0.000622	1.95E-05	0.002597	0.00279	0.020062	0.011434	0.01473	0.001626	0.007494	0.009057	0.015914
125	0.00065	0.000562	1.77E-05	0.00235	0.002525	0.01815	0.010344	0.013327	0.001471	0.00678	0.008194	0.014397
150	0.00065	0.000562	1.77E-05	0.00235	0.002525	0.01815	0.010344	0.013327	0.001471	0.00678	0.008194	0.014397
175	0.00065	0.000562	1.77E-05	0.00235	0.002525	0.01815	0.010344	0.013327	0.001471	0.00678	0.008194	0.014397
200	0.00065	0.000562	1.77E-05	0.00235	0.002525	0.01815	0.010344	0.013327	0.001471	0.00678	0.008194	0.014397
225	0.000581	0.000503	1.58E-05	0.002102	0.002259	0.016238	0.009254	0.011923	0.001316	0.006065	0.007331	0.01288
250	0.000581	0.000503	1.58E-05	0.002102	0.002259	0.016238	0.009254	0.011923	0.001316	0.006065	0.007331	0.01288
275	0.000581	0.000503	1.58E-05	0.002102	0.002259	0.016238	0.009254	0.011923	0.001316	0.006065	0.007331	0.01288
300	0.000581	0.000503	1.58E-05	0.002102	0.002259	0.016238	0.009254	0.011923	0.001316	0.006065	0.007331	0.01288
500	0.000478	0.000414	1.3E-05	0.001731	0.00186	0.01337	0.00762	0.009817	0.001084	0.004994	0.006036	0.010605
700	0.000342	0.000296	9.3E-06	0.001236	0.001328	0.009546	0.00544	0.007009	0.000774	0.003566	0.00431	0.007572
900	0.000171	0.000148	4.64E-06	0.000617	0.000663	0.004766	0.002716	0.003499	0.000386	0.00178	0.002152	0.003781
1100	0.000171	0.000148	4.64E-06	0.000617	0.000663	0.004766	0.002716	0.003499	0.000386	0.00178	0.002152	0.003781
1300	0.000171	0.000148	4.64E-06	0.000617	0.000663	0.004766	0.002716	0.003499	0.000386	0.00178	0.002152	0.003781

Table 5.4 Simulation Result For Heat Radiation In Aghigho Station In Year 2000.Stack Efficiency 84%

Month	January	Febuary	March	April	May	June	July	August	September	October	November	December
Vol.(m3/s)	1.13E-02	1.05E-02	2.66E-04	4.05E-02	5.11E-02	2.76E-01	1.67E-01	2.18E-01	2.76E-02	1.15E-01	1.53E-01	2.70E-01
Distance (m)	Qfd(kW/m2)	Qfd(kW/m2)	Qfd(kW/m2)	Qfd(kW/m2)	Qfd(kW/m2)	Qfd(kW/m2)	Qfd(kW/m2)	Qfd(kW/m2)	Qfd(kW/m2)	Qfd(kW/m2)	Qfd(kW/m2)	Qfd(kW/m2)
25	0.000761	0.000659	2.07E-05	0.002753	0.002958	0.021267	0.01212	0.015615	0.001724	0.007944	0.009601	0.016869
50	0.000761	0.000659	2.07E-05	0.002753	0.002958	0.021267	0.01212	0.015615	0.001724	0.007944	0.009601	0.016869
75	0.000761	0.000659	2.07E-05	0.002753	0.002958	0.021267	0.01212	0.015615	0.001724	0.007944	0.009601	0.016869
100	0.000761	0.000659	2.07E-05	0.002753	0.002958	0.021267	0.01212	0.015615	0.001724	0.007944	0.009601	0.016869
125	0.000689	0.000596	1.87E-05	0.002491	0.002676	0.01924	0.010965	0.014127	0.00156	0.007187	0.008686	0.015261
150	0.000689	0.000596	1.87E-05	0.002491	0.002676	0.01924	0.010965	0.014127	0.00156	0.007187	0.008686	0.015261
175	0.000689	0.000596	1.87E-05	0.002491	0.002676	0.01924	0.010965	0.014127	0.00156	0.007187	0.008686	0.015261
200	0.000689	0.000596	1.87E-05	0.002491	0.002676	0.01924	0.010965	0.014127	0.00156	0.007187	0.008686	0.015261
225	0.000616	0.000533	1.68E-05	0.002228	0.002394	0.017213	0.00981	0.012639	0.001395	0.00643	0.007771	0.013654
250	0.000616	0.000533	1.68E-05	0.002228	0.002394	0.017213	0.00981	0.012639	0.001395	0.00643	0.007771	0.013654
275	0.000616	0.000533	1.68E-05	0.002228	0.002394	0.017213	0.00981	0.012639	0.001395	0.00643	0.007771	0.013654
300	0.000616	0.000533	1.68E-05	0.002228	0.002394	0.017213	0.00981	0.012639	0.001395	0.00643	0.007771	0.013654
500	0.000507	0.000439	1.38E-05	0.001835	0.001971	0.014173	0.008077	0.010406	0.001149	0.005294	0.006398	0.011242
700	0.000362	0.000314	9.86E-06	0.00131	0.001408	0.01012	0.005767	0.00743	0.00082	0.00378	0.004568	0.008027
900	0.000181	0.000157	4.92E-06	0.000654	0.000703	0.005052	0.002879	0.00371	0.00041	0.001887	0.002281	0.004008
1100	0.000181	0.000157	4.92E-06	0.000654	0.000703	0.005052	0.002879	0.00371	0.00041	0.001887	0.002281	0.004008
1300	0.000181	0.000157	4.92E-06	0.000654	0.000703	0.005052	0.002879	0.00371	0.00041	0.001887	0.002281	0.004008
1500	0.000181	0.000157	4.92E-06	0.000654	0.000703	0.005052	0.002879	0.00371	0.00041	0.001887	0.002281	0.004008

Table 5.5: Simulation Results For Heat Radiation In Ubagi Station For Year 2000. Stack Efficiency Of 64%

Month	January	Febuary	March	April	May	June	July	August	September	October	November	December
Vol. (m3/s)	9.01	4.86	2.83	4.33	8.55	5.50E-01	2.83	9.07	8.71	8	5.03	7.29
Distance (m)	Qfd(kW/m2)	Qfd(kW/m2)	Qfd(kW/m2)	Qfd(kW/m2)	Qfd(kW/m2)	Qfd(kW/m2)	Qfd(kW/m2)	Qfd(kW/m2)	Qfd(kW/m2)	Qfd(kW/m2)	Qfd(kW/m2)	Qfd(kW/m2)
25	0.546218	0.261307	0.250722	0.258796	0.588863	0.032701	0.181965	0.571863	0.477468	0.463097	0.422624	0.446104
50	0.546218	0.261307	0.250722	0.258796	0.588863	0.032701	0.181965	0.571863	0.477468	0.463097	0.422624	0.446104
75	0.546218	0.261307	0.250722	0.258796	0.588863	0.032701	0.181965	0.571863	0.477468	0.463097	0.422624	0.446104
100	0.546218	0.261307	0.250722	0.258796	0.588863	0.032701	0.181965	0.571863	0.477468	0.463097	0.422624	0.446104
125	0.494161	0.236403	0.226827	0.234132	0.532742	0.029585	0.164623	0.517362	0.431963	0.418962	0.382347	0.403589
150	0.494161	0.236403	0.226827	0.234132	0.532742	0.029585	0.164623	0.517362	0.431963	0.418962	0.382347	0.403589
175	0.494161	0.236403	0.226827	0.234132	0.532742	0.029585	0.164623	0.517362	0.431963	0.418962	0.382347	0.403589
200	0.494161	0.236403	0.226827	0.234132	0.532742	0.029585	0.164623	0.517362	0.431963	0.418962	0.382347	0.403589
225	0.442105	0.2115	0.202933	0.209468	0.476621	0.026468	0.147281	0.462861	0.386459	0.374827	0.342069	0.361073
250	0.442105	0.2115	0.202933	0.209468	0.476621	0.026468	0.147281	0.462861	0.386459	0.374827	0.342069	0.361073
275	0.442105	0.2115	0.202933	0.209468	0.476621	0.026468	0.147281	0.462861	0.386459	0.374827	0.342069	0.361073
300	0.442105	0.2115	0.202933	0.209468	0.476621	0.026468	0.147281	0.462861	0.386459	0.374827	0.342069	0.361073
500	0.36402	0.174144	0.16709	0.172471	0.392439	0.021793	0.121268	0.38111	0.318202	0.308625	0.281652	0.2973
700	0.259906	0.124337	0.119301	0.123143	0.280198	0.01556	0.086584	0.272109	0.227193	0.220355	0.201097	0.212269
900	0.129765	0.062078	0.059564	0.061482	0.139896	0.007769	0.043229	0.135857	0.113432	0.110018	0.100402	0.10598
1100	0.129765	0.062078	0.059564	0.061482	0.139896	0.007769	0.043229	0.135857	0.113432	0.110018	0.100402	0.10598
1300	0.129765	0.062078	0.059564	0.061482	0.139896	0.007769	0.043229	0.135857	0.113432	0.110018	0.100402	0.10598
1500	0.129765	0.062078	0.059564	0.061482	0.139896	0.007769	0.043229	0.135857	0.113432	0.110018	0.100402	0.10598

Table 5.6: Simulation Results For Heat Radiation In Ubagi Station For Year 2000. Stack Efficiency Of 74%

Month	January	February	March	April	May	June	July	August	September	October	November	December
Vol. (m3)	9.01	4.86	2.83	4.33	8.55	5.50E-01	2.83	9.07	8.71	8	5.03	7.29
Distance (m)	Distance (m)	Qfd(kW/m2)	Qfd(kW/m2)	Qfd(kW/m2)	Qfd(kW/m2)	Qfd(kW/m2)	Qfd(kW/m2)	Qfd(kW/m2)	Qfd(kW/m2)	Qfd(kW/m2)	Qfd(kW/m2)	Qfd(kW/m2)
25	0.581115	0.278001	0.26674	0.275331	0.626484	0.03479	0.193591	0.608398	0.507973	0.492684	0.449625	0.474605
50	0.581115	0.278001	0.26674	0.275331	0.626484	0.03479	0.193591	0.608398	0.507973	0.492684	0.449625	0.474605
75	0.581115	0.278001	0.26674	0.275331	0.626484	0.03479	0.193591	0.608398	0.507973	0.492684	0.449625	0.474605
100	0.581115	0.278001	0.26674	0.275331	0.626484	0.03479	0.193591	0.608398	0.507973	0.492684	0.449625	0.474605
125	0.525733	0.251507	0.241319	0.24909	0.566778	0.031475	0.175141	0.550415	0.459561	0.445729	0.406774	0.429373
150	0.525733	0.251507	0.241319	0.24909	0.566778	0.031475	0.175141	0.550415	0.459561	0.445729	0.406774	0.429373
175	0.525733	0.251507	0.241319	0.24909	0.566778	0.031475	0.175141	0.550415	0.459561	0.445729	0.406774	0.429373
200	0.525733	0.251507	0.241319	0.24909	0.566778	0.031475	0.175141	0.550415	0.459561	0.445729	0.406774	0.429373
225	0.47035	0.225012	0.215898	0.22285	0.507071	0.028159	0.156691	0.492433	0.411149	0.398774	0.363923	0.384141
250	0.47035	0.225012	0.215898	0.22285	0.507071	0.028159	0.156691	0.492433	0.411149	0.398774	0.363923	0.384141
275	0.47035	0.225012	0.215898	0.22285	0.507071	0.028159	0.156691	0.492433	0.411149	0.398774	0.363923	0.384141
300	0.47035	0.225012	0.215898	0.22285	0.507071	0.028159	0.156691	0.492433	0.411149	0.398774	0.363923	0.384141
500	0.387276	0.18527	0.177766	0.18349	0.417512	0.023186	0.129016	0.405459	0.338531	0.328342	0.299647	0.316294
700	0.276511	0.132281	0.126923	0.13101	0.298099	0.016554	0.092116	0.289493	0.241708	0.234433	0.213945	0.225831
900	0.138055	0.066045	0.063369	0.06541	0.148833	0.008265	0.045991	0.144537	0.120679	0.117046	0.106817	0.112751
1100	0.138055	0.066045	0.063369	0.06541	0.148833	0.008265	0.045991	0.144537	0.120679	0.117046	0.106817	0.112751
1300	0.138055	0.066045	0.063369	0.06541	0.148833	0.008265	0.045991	0.144537	0.120679	0.117046	0.106817	0.112751

Table 5.7 Simulation Result For Heat Radiation In Ubagi Station In Year 2000.Stack Efficiency 84%

Month	January	Febuary	March	April	May	June	July	August	September	October	November	December
Vol. (m3/s)	9.01	4.86	2.83	4.33	8.55	5.50E-01	2.83	9.07	8.71	8	5.03	7.29
Distance (m)	Qfd(kW/m2)	Qfd(kW/m2)	Qfd(kW/m2)	Qfd(kW/m2)	Qfd(kW/m2)	Qfd(kW/m2)	Qfd(kW/m2)	Qfd(kW/m2)	Qfd(kW/m2)	Qfd(kW/m2)	Qfd(kW/m2)	Qfd(kW/m2)
25	0.616012	0.294696	0.282759	0.291865	0.664105	0.036879	0.205216	0.644934	0.538477	0.52227	0.476626	0.503106
50	0.616012	0.294696	0.282759	0.291865	0.664105	0.036879	0.205216	0.644934	0.538477	0.52227	0.476626	0.503106
75	0.616012	0.294696	0.282759	0.291865	0.664105	0.036879	0.205216	0.644934	0.538477	0.52227	0.476626	0.503106
100	0.616012	0.294696	0.282759	0.291865	0.664105	0.036879	0.205216	0.644934	0.538477	0.52227	0.476626	0.503106
125	0.557304	0.26661	0.255811	0.264049	0.600813	0.033365	0.185658	0.583469	0.487158	0.472496	0.431202	0.455158
150	0.557304	0.26661	0.255811	0.264049	0.600813	0.033365	0.185658	0.583469	0.487158	0.472496	0.431202	0.455158
175	0.557304	0.26661	0.255811	0.264049	0.600813	0.033365	0.185658	0.583469	0.487158	0.472496	0.431202	0.455158
200	0.557304	0.26661	0.255811	0.264049	0.600813	0.033365	0.185658	0.583469	0.487158	0.472496	0.431202	0.455158
225	0.498595	0.238525	0.228863	0.236233	0.537522	0.02985	0.166101	0.522004	0.435839	0.422721	0.385777	0.40721
250	0.498595	0.238525	0.228863	0.236233	0.537522	0.02985	0.166101	0.522004	0.435839	0.422721	0.385777	0.40721
275	0.498595	0.238525	0.228863	0.236233	0.537522	0.02985	0.166101	0.522004	0.435839	0.422721	0.385777	0.40721
300	0.498595	0.238525	0.228863	0.236233	0.537522	0.02985	0.166101	0.522004	0.435839	0.422721	0.385777	0.40721
500	0.410533	0.196396	0.188441	0.194509	0.442584	0.024578	0.136764	0.429807	0.358861	0.34806	0.317641	0.335288
700	0.293116	0.140225	0.134545	0.138878	0.316	0.017548	0.097648	0.306878	0.256223	0.248511	0.226792	0.239392
900	0.146345	0.070011	0.067175	0.069338	0.157771	0.008761	0.048753	0.153216	0.127925	0.124075	0.113232	0.119522
1100	0.146345	0.070011	0.067175	0.069338	0.157771	0.008761	0.048753	0.153216	0.127925	0.124075	0.113232	0.119522
1300	0.146345	0.070011	0.067175	0.069338	0.157771	0.008761	0.048753	0.153216	0.127925	0.124075	0.113232	0.119522
1500	0.146345	0.070011	0.067175	0.069338	0.157771	0.008761	0.048753	0.153216	0.127925	0.124075	0.113232	0.119522

5.2 DISCUSSION OF RESULTS

Normal atmospheric temperature ranges between 25 – 35°C but during gas flaring heat is radiated thereby altering the normal temperature of the atmosphere. Some of the fundamental aspects of the anticipated repercussion of heat radiated are eventual warming of the atmosphere above normal atmospheric temperature, changes in regional rain patterns, melting glaciers and thermal expansion of sea water (Andy, 2003).

From the experimental values shown in table 5.1 of results, it could be observed that the heat radiation from the flare point varies from month to month and are unpatterned. These values are resultant of the heat radiation from the flare point. The simulation results are presented in tables 5.2-5.7. It could be observed from the simulation results that the heat radiation from gas flaring for different stations increases with increase in volume of gas flared, increase in stack efficiency and decreases with increase in distance from flare. For example in the month of May at a distance of 100m the quantity of heat radiated is 0.00262287 kW/m^2 while at a distance of 200m the quantity of heat radiated is 0.0023729 kW/m^2 for Aghigho station. Also at a stack efficiency of 64% in the month of May, in Aghigho station at a distance of 100m, the quantity of heat radiated is 0.00262287 kW/m^2. While for that same month at the same distance in the same station for stack efficiency of 74%, the quantity of heat radiated is 0.00279044 kW/m^2. Also the highest volume of gas in Aghigho station was flared in month of June which resulted in the highest quantity of heat radiation generated in that station for Year 2000.

The experimental results conform with the simulated results to an extent. The differences between the experimental results and the simulated results could be as a result of the assumptions made during the modelling, the unpatterned nature of the experimental results and the fact that the experimental results are a measure of the quantity of heat released into the atmosphere while the simulation result is an instantaneous value.

5.3 Conclusion

From computer simulation of the model, it can be deduced that increase in volume of gas flared results to an increase in the quantity of heat radiation. An increase in the distance from flare also leads to an increase in the quantity of heat radiated and as a result, within the vicinity of gas flare, human habitation is unsafe.

The result obtained from the model can be used to determine the possible effects of gas flaring on the environment as the results obtained can be compared with the minimum quantity of heat plants and animals can withstand before degradation. The model has helped in quantifying the pollution potential of heat radiation from gas flaring.

5.4 RECOMMENDATION

The government should make effort to improve the local market for gas by raising the domestic consumption of gas in the country. Oil companies should include gas collection facilities to all field and installation of pipe network that will link the gas station to process industries for industrial utilisation of gas. This will help to prevent enormous flaring of gas – a vital natural resource.

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APPENDIX A

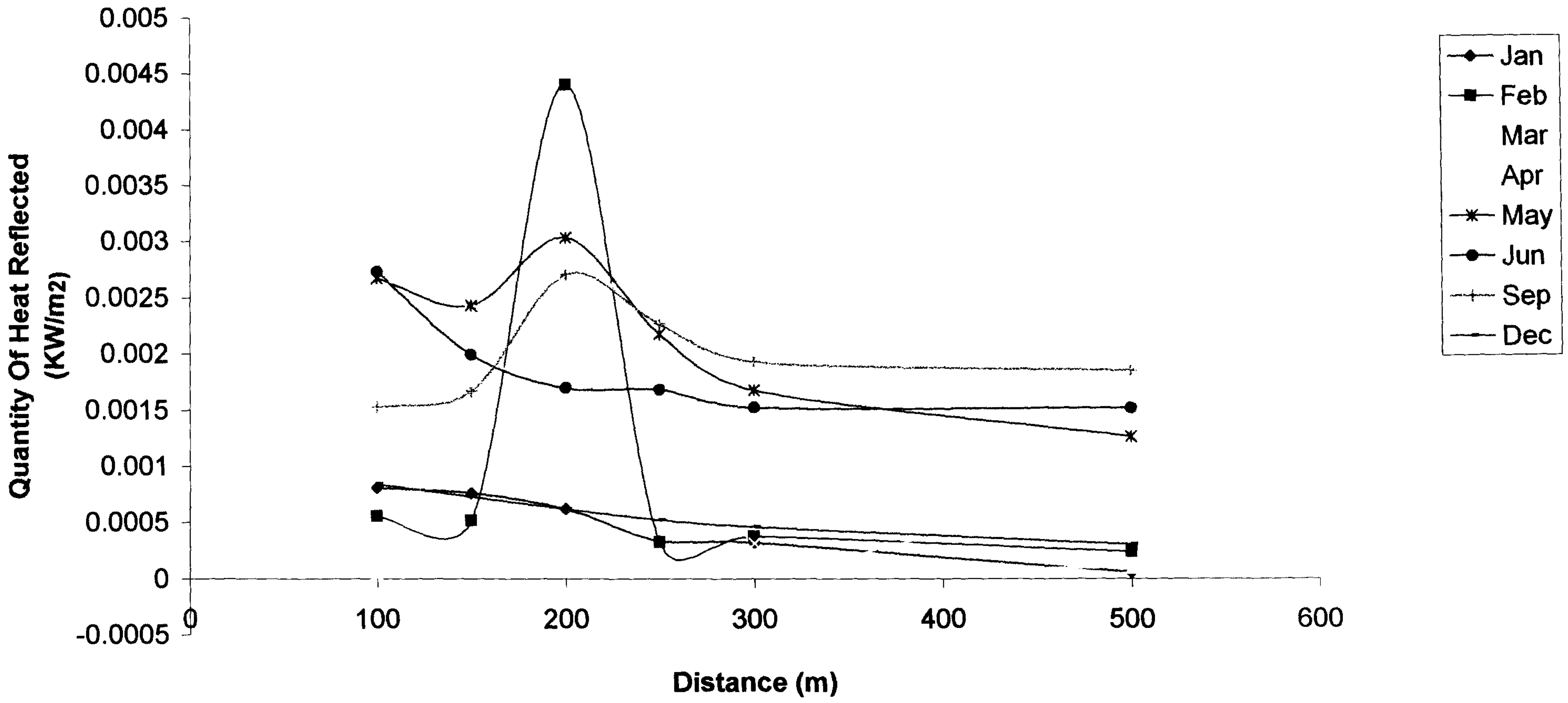

Figure 5.1Graphical Representation Of Experimental Data On Heat Radiation In Aghigho Station In Year 2000

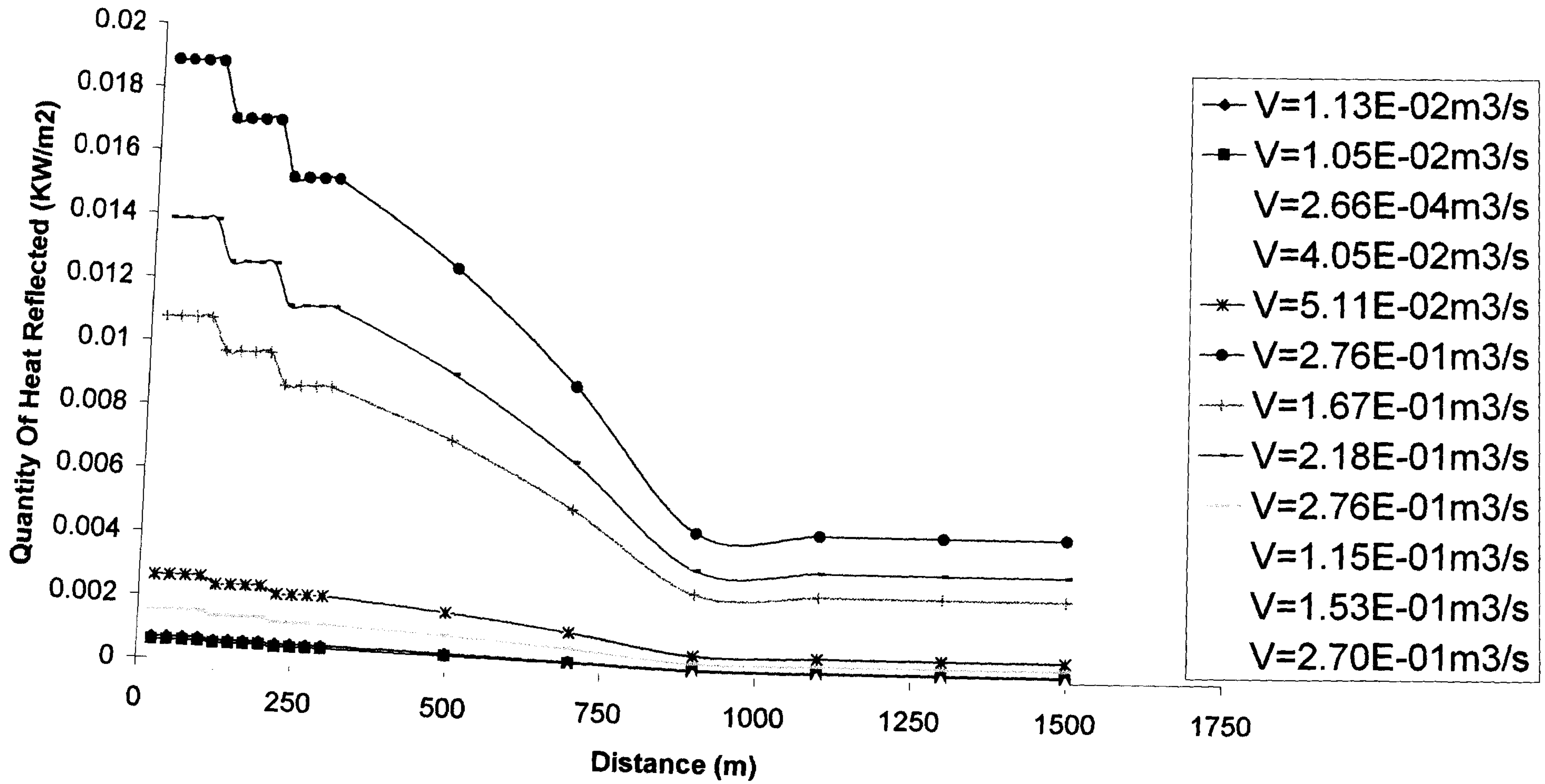

Figure 5.2 Graphical Representation Of Heat Radiation In Aghigho For Stack Efficiency of 64%, Year 2000

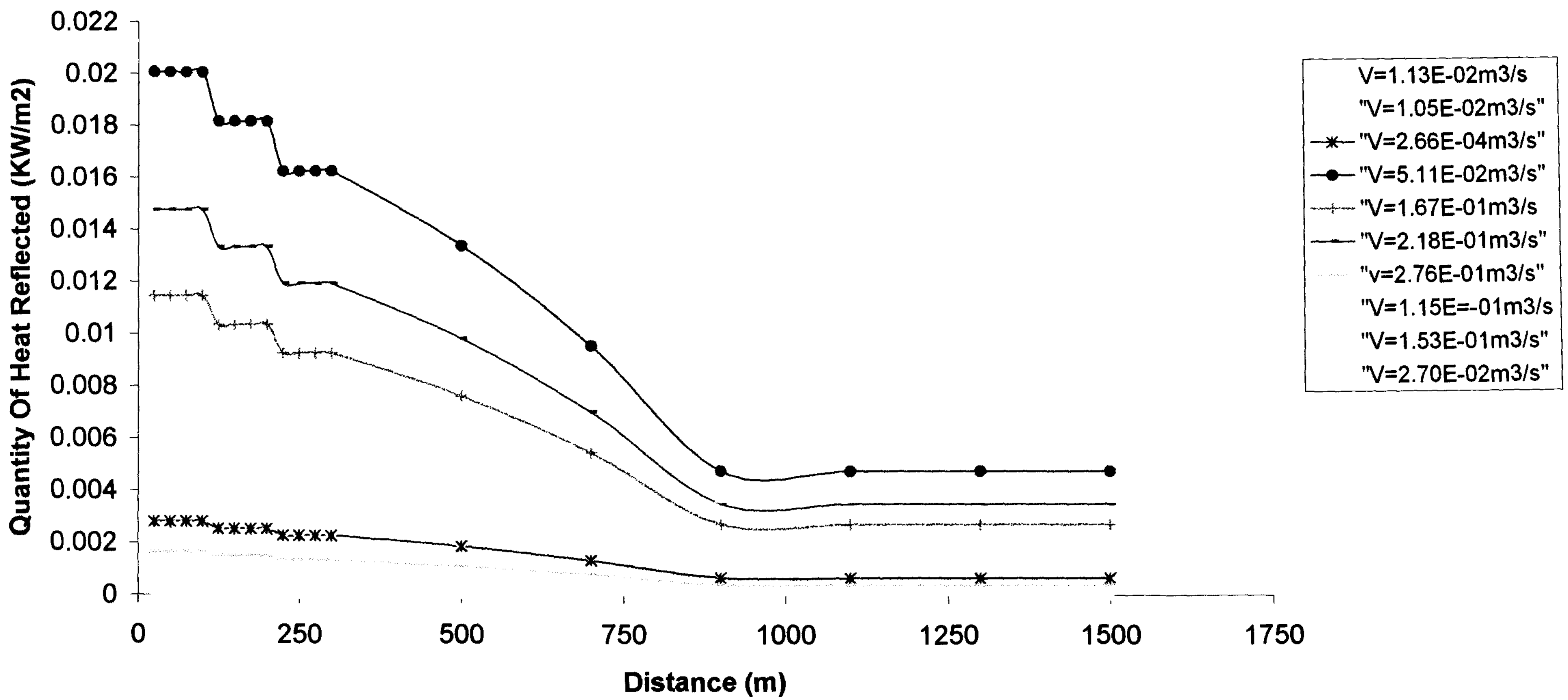

Figure 5.3 Graphical Representation Of Heat Radiation In Aghigho For Stack Efficiency of 74%, Year 2000

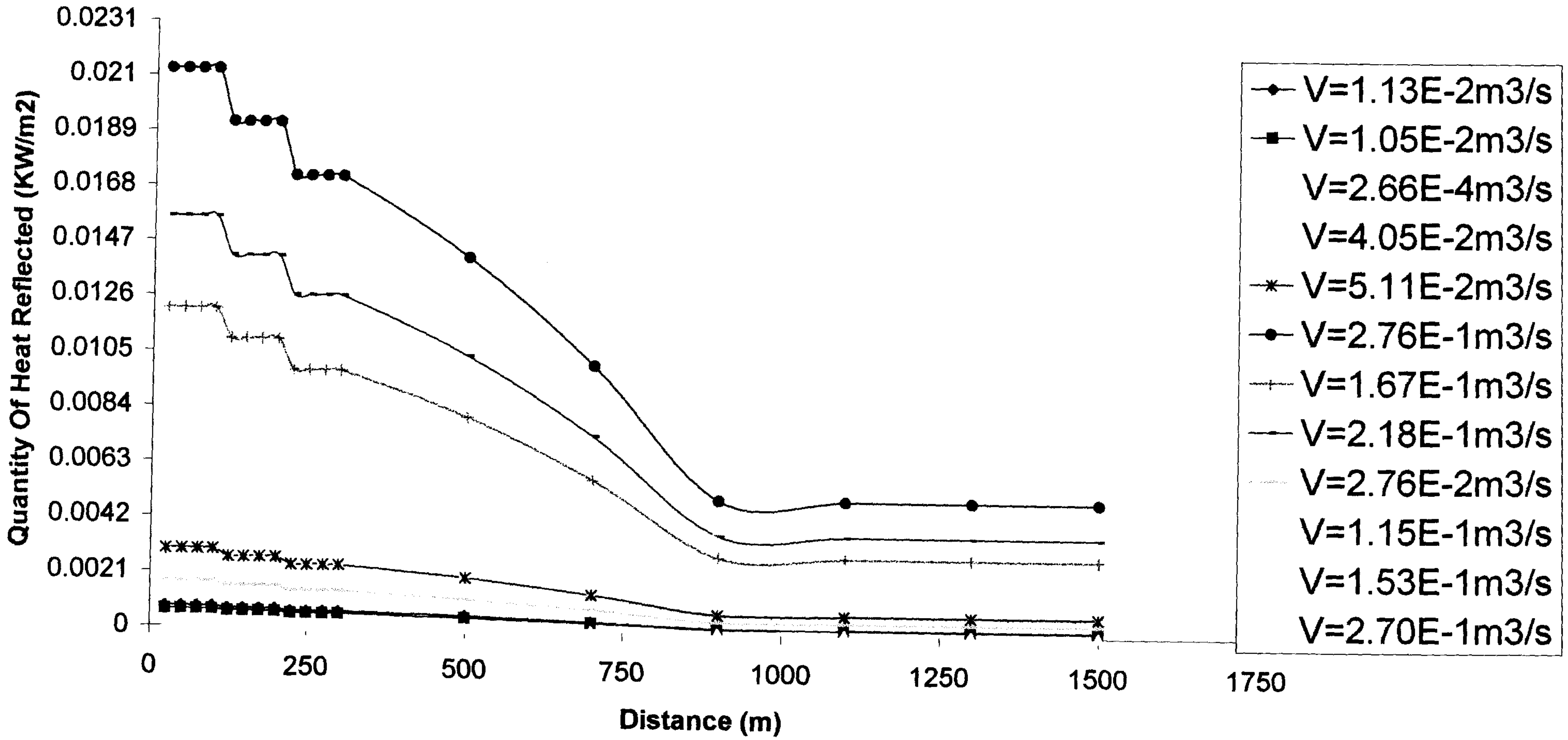

Figure 5.4 Graphical Representation Of Heat Radiation In Aghigho For Stack Efficiency of 84%, Year 2000

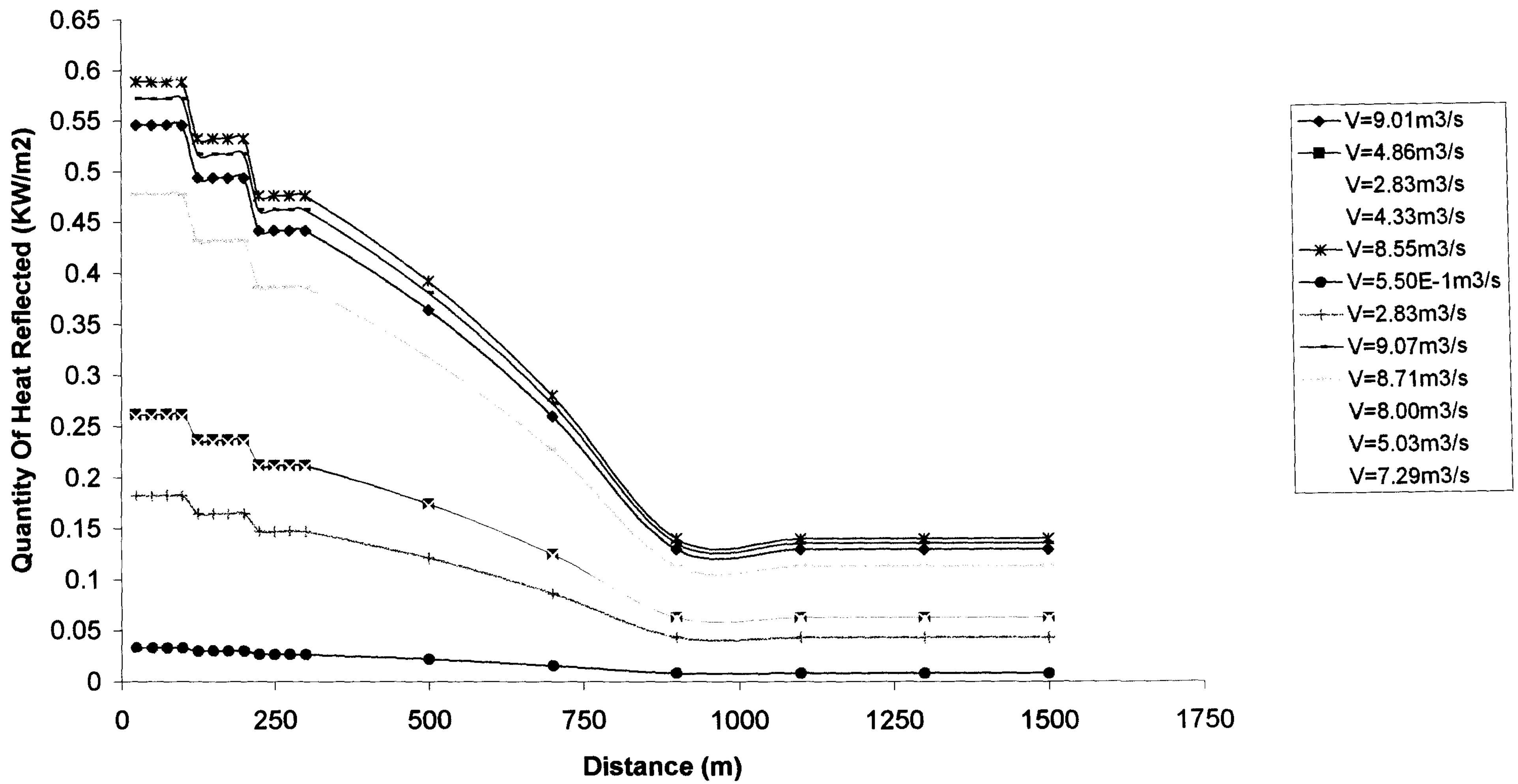

Figure 5.5 Graphical Representation Of Heat Radiation In Ubhagi For Stack Efficiency of 64%, Year 2000

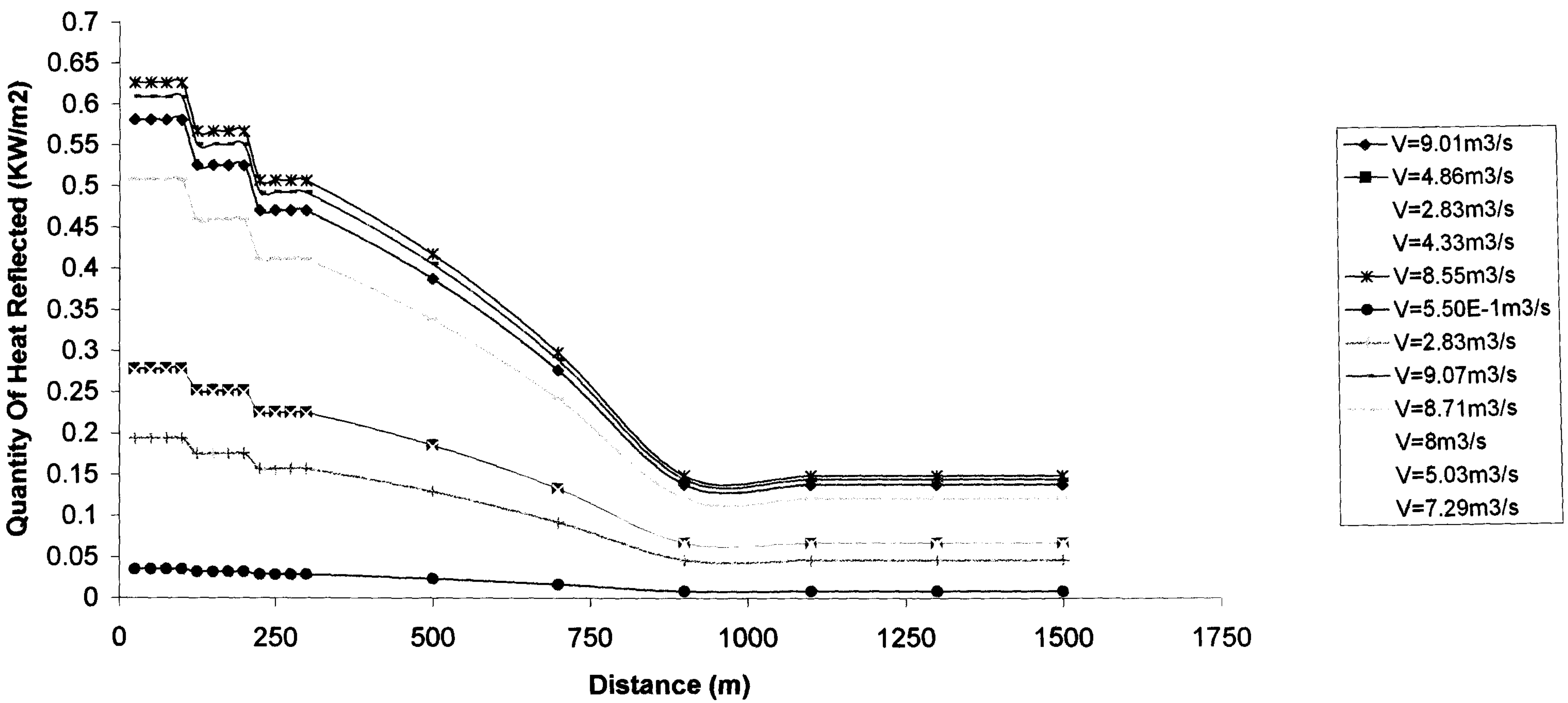

Figure 5.6 Graphical Representation Of Heat Radiation In Ubagi For Stack Efficiency of 74%, Year 2000

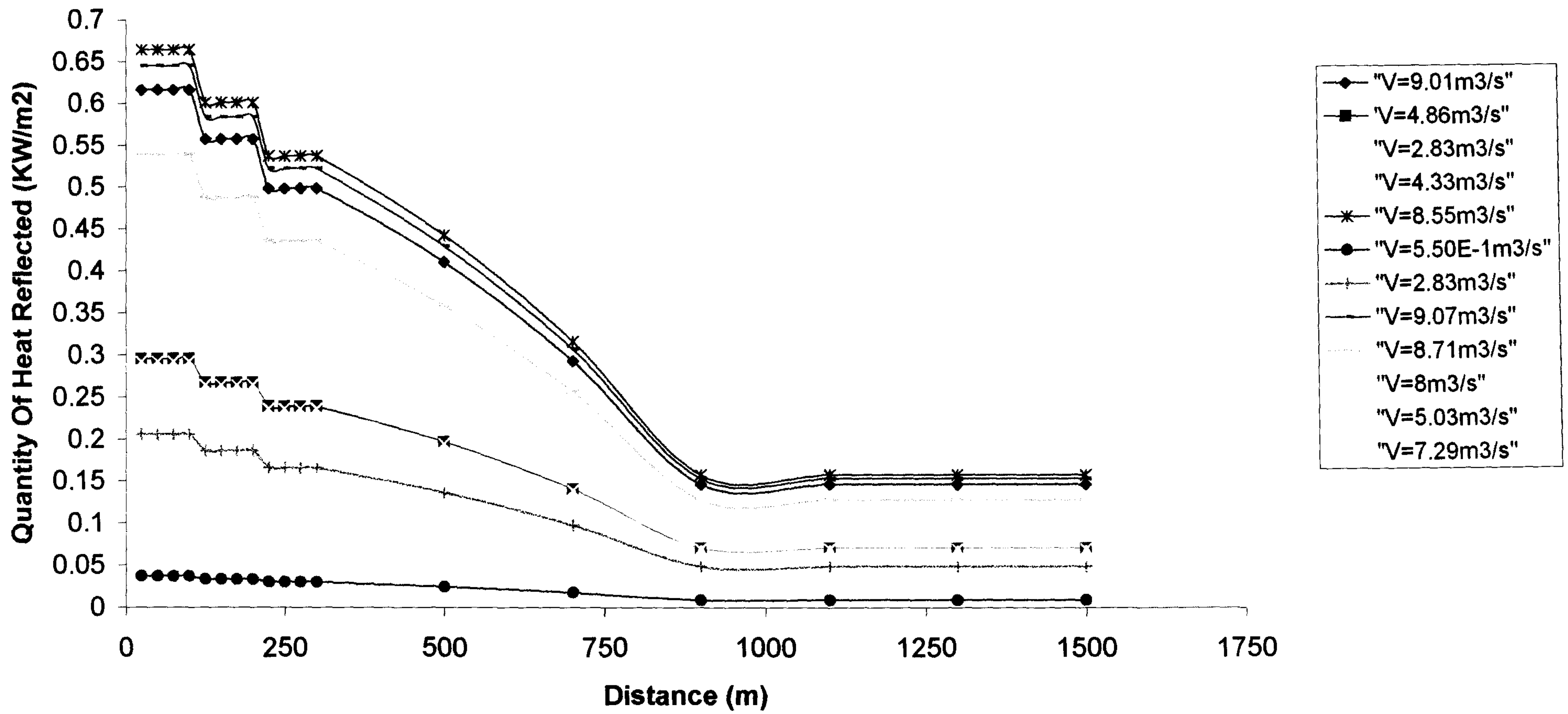

Figure 5.7 Graphical Representation Of Heat Radiation In Ubagi For Stack Efficiency of 84%, Year 2000

APPENDIX B

```
Private arrayV_(4), arrayTs_(4), arrayTa_(4), arrayHr_(4), arrayHsp_(4), arrayDw_(4) As Double
Dim bisi(12) As Concent
Private i As Integer
'Private V_, Ts_, Ta_, Hr_, Hsp_, Dw_, Iref_, dT_, P_ As Double
Private V_, Ts_, Ta_, r_, Cp_, Da_, a_, c_, Se_, dT_ As Double
Private X, Y, z As Double
Private anSt(4, 12, 20) As Double


Private Sub Form_Load()
   Me.Width = 7545
   Me.Height = 4095

   addComboItems
   setTitle
   textFlds
End Sub
Private Function getValues(Index As Integer) As Double
   Dim r As Integer
   Dim ju As Integer
   ju = Index
   'V_, Ts_, Ta_, r_, Cp_, Da_, a_, c_, Se_, dT_

   V_ = ((val(V(ju%)) * 10 ^ 3) / 2592000)
   vol = V_
   Ts_ = (val(Ts(ju%)) + 0)
   Ta_ = (val(Ta(ju%)) + 273)
   r_ = val(rval)
   Cp_ = val(Cp)
   Da_ = val(Da)
   a_ = val(a)
   c_ = val(c)
   Se_ = val(Se)
   dT_ = val(Dt)

  X = 1E-19
  For r = 0 To 0
     answer(r, 0) = Li
     If (X < 300) Then
        X = X + 25
     ElseIf (X >= 300) Then
        X = X + (20 * 10)
     End If
  Next r

  X = 25
  For r = 1 To 19
     answer(r, 0) = Li
     If (X < 300) Then
        X = X + 25
     ElseIf (X >= 300) Then
        X = X + (20 * 10)
     End If
  Next r
  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
   'Hr(0).Left = T(0).Left + station(0).Width + 200
   'Hsp(0).Left = Hr(0).Left + station(0).Width + 200
   'Dw(0).Left = Hsp(0).Left + station(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
   'Hr(0).Top = station(0).Top
   'Hsp(0).Top = station(0).Top
   'Dw(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 Hr(i%)
      'Hr(i%).Left = Hr(0).Left
      'Hr(i%).Top = station(i%).Top
      'Hr(i%).Visible = True

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

      'Load Dw(i%)
      'Dw(i%).Left = Dw(0).Left
      'Dw(i%).Top = station(i%).Top
      'Dw(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) = "Rel. H"
    title(5) = "Sp. H"
    title(6) = "Dw"

    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
      'Hr(sta).Enabled = True
      'Hsp(sta).Enabled = True
      'Dw(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
      'Hr(sta).Enabled = False
      'Hsp(sta).Enabled = False
      'Dw(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 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 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 D() As Double
    D = Da_ * Ta_ / Ts_
End Function
Private Function Li() As Double
    Dim func1, func2, func3, func4, func4_ As Double
    Dim alpha As Double
    Dim Qfd As Double
    Dim Rb As Double
    Rb = 0.15
    alpha = 0.225
    If X <= 100 Then
       alpha = 0.4
    ElseIf X > 100 And X <= 200 Then
       alpha = 0.5
    ElseIf X > 200 And X <= 300 Then
       alpha = 0.6
    ElseIf X > 300 And X <= 400 Then
       alpha = 0.7
    ElseIf X > 400 And X <= 500 Then
       alpha = 0.75
    ElseIf X > 500 And X <= 400 Then
       alpha = 0.8
    ElseIf X > 400 And X <= 500 Then
       alpha = 0.85
    ElseIf X > 500 And X <= 600 Then
       alpha = 0.9
    ElseIf X > 600 And X <= 700 Then
       alpha = 0.95
    ElseIf X > 700 And X <= 800 Then
       alpha = 1#
    ElseIf X > 800 Then
       alpha = 1.2
    End If
    func1 = (r_ * Cp_ * Ta_ * X * (r_ * D() + Da_) + D() * dT_ * (0.99 + 0.0109074 * Se_) * V_ *
c_ * (Ts_ - Ta_)) ^ 0.4
    func2 = D() ^ 0.4 * (dT_ * (0.99 + 0.0109074 * Se_) * V_ * c_ * (Ts_ - Ta_)) ^ 1.4
    func3 = (r_ * X * Cp_ * Ta_ + dT_ * (0.99 + 0.0109074 * Se_) * V_ * c_ * (Ts_ - Ta_)) ^ 0.6
    func4 = (145.32 * func1 * func3 * (X ^ 0.4) / func2) '^ (1 / 0.078)
    Qfd = (func4) * (1 - alpha * (1 - a_))
    Qfd = Qfd - alpha * Qfd * (1 - a_)
    Li = Qfd * (10 ^ -10)
End Function


End Sub
```