Oil Exploration and Climate Change: A Case Study of Heat Radiation from Gas Flaring in the Niger Delta Area of Nigeria

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Additional information is available at the end of the chapter

1. Introduction

Nigeria like most other developing countries in the early part of the 70s was engaged in intensive natural resource exploitation as a way of stimulating economic growth (Ajayi, 1999; Abdulkareem et al, 2009). As at 1976, about 10 years from the start of oil exploration in the Niger-Delta area of Nigeria, figures available from the office of federal statistics stated that 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 (Olukoga, 2002; Tolulope, 2004; Abdulkareem and Odigure, 2006). Also total export peaked at 2 millions barrels per day of crude oil with price range of 18-22US dollars per barrel (Odigure and Abdulkareem, 2006). It is worth of mentioning that the current price per barrel of oil is now in the range of 80-110 US dollars (Ufarana, 2004; Akpan, 2009). This has created more opportunities for the development of new fields and increase granting of mining licenses and intensive exploration of oil mineral resources in the country (Ajayi, 1999; Abenege, 2004). 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 is estimated at two billion cubic feet per day (scf/d) or 56,600 m³, the highest in any member nation of OPEC (Ageh et al, 2009; Ajayi, 2009). The quantity of gas flared in Nigeria is equivalent to the total annual power generation in the sub-Saharan Africa 'according to World Bank'(Odigure, 2001; UNDP/World bank report, 2004; Akpan, 2009). Nigeria is said to have natural gas reserves of 100 trillion standard cubic feet (about 2.832 trillion cubic meters), with about 45 trillion standard cubic reserves in the Niger-Delta Area of Nigeria (Ufarana, 2004; Tolulope, 2004). In energy terms, the quantity of natural gas in Nigeria is said to be more than twice the

quantity of crude oil (Agbalino and Eyinal, 1997; Ajayi, 1999; Abdulkareem and Odigure, 2006) .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 (Akpan, 2009). Consequently, petroleum experts often describe Nigeria as a natural gas province with some oil in it; this put the country in the ten top nations in the world in terms of natural gas reserves (Abowei et al., 1997, Abdulkareem, 1999; Oni, 2011). Though, there is no proper record of natural gas production per year in Nigeria, however the total Nigeria natural gas production is put in the range of 22-25 billion cubic meters per year (Abdulkareem and Odigure, 2006). Around 18 billion cubic meters of the total gas produced is associated gas, most of which is flared , with small amount re-injected into the sandstone sponge while the remaining is sold to electricity generating stations and industries (Abdulkareem and Odigure, 2010). It has been reported that about 3 billion cubic meters per year of non associated gas is currently trapped for industrial consumptions, this is an indication that the level of gas utilization on Nigeria is very low (Akpan, 2009; Abdulkareem et al., 2010). Gas utilization is for now limited to some small quantities being used as fuel for petroleum operations for enhancement of oil recovery project, for pressure maintenance in some industrial processes on a relatively modest scale and for power generation (Reymond, 2007; Udetal et al., 2007). Gas flaring is therefore 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 (Abdulkareem and Odigure, 2002; Odigure et al., 2003; Ufarana, 2004).

The Niger-Delta oil fields of Nigeria covers about 70,000 square kilometer and is one of the world's largest wetlands, which houses Nigeria's proven gas reserves, estimated to be 120 trillion cubic feet (Abdulkareem, 1999; Uyigue and Agho, 2005; Onyiah, 2005). 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 whole, the accompanying socio-economic and ecological fallout remain problematic (Alakpodia, 1980; Akpan, 2009). The public considers the oil-producing companies operating in the Niger-Delta oil fields responsible for polluting the environment by way or relentless flaring and venting of gas in to the environment, heat radiation, noise radiation, oil spillage, water pollution, site clearing, deforestation and destruction of the flora and fauna and consequences disturbances of the ecosystem in the 70,000 square kilometers Niger-Delta wetland (Ifeanyichukwu, 2002; Odigure and Abdulkareem, 2002; Abdulkareem et al., 2011). The situation that led to growing anger among the local peoples on the damages caused to their health and ecosystem by oil exploration activities, especially gas flaring and crude oil spillage (Oyekunle, 1995; Onosode, 1996; Abdulkareem et al., 2011). It has also been noted that there are currently 100 gas flaring sites, some of which have been burning ceaselessly for 40 years. Each one of these bonfires as shown in Fig 1 has an adverse effect on the inhabitants and the natural environment (Ifeanyichukwu, 2002; Oyekunle, 1995). 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 (Abdulkareem and Odigure, 2006). 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 (FEPA Report, 1998; UNDP/World Bank report, 2004). Flared gas also releases hazardous substances into the environment that heighten the problem of the depletion of the ozone layer (Chimaroke, 2004). The attendant "green house effect" is one of the most frightening environmental 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 (Ikelegbe, 1993). 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 (Oyekunle, 1999; Akpan, 2009). Combustion of associated gas during gas flaring also releases heat into the environment. The heat radiation from gas flaring greatly affects the surrounding environment and particular crops planted within the vicinity of gas flare stations (Abdulkareem and Odigure, 2002). It also has a devastating effect on microorganisms and aquatic life. Heat radiation from gas flaring also causes an increase in heat waves hence there is the possibility that habitants of Niger-Delta Area, where the gas flaring stations are located will suffer heart stroke, heart attacks and other ailments aggravated by the heat (Odigure et al., 2003). For instance, it has been reported that 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 (Aduku, 1997; Olukoga, 2002; Abenege, 2004) . Heat radiation from gas flaring also contributed to the increment in the soil temperature, which destroys the plant thereby affecting the ecosystem since plants absorb CO_2 in the atmosphere (Kearns et al., 2000; Tolulope, 2004; Tzimas et al., 2007). The world health organisation advised the Nigerian government to address the problem of gas flaring by paying close attention to the activities of companies engaged in gas flaring and the environmental problems associated with their exploratory methods and to invite experts from developed countries to work with Nigerian professionals and environmentalists to proffer remedy (Global gas reduction initiative, 2002; UNDP/World bank report, 2004; Ufarana, 2004). 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. The harmful effects of gas flaring and inability of the oil companies and government to quantify the resultants effects of gas flaring on the environment has led to strain relationship between the oil producing companies and the people of Niger-Delta Area of Nigeria. To control the activities of oil companies in the Niger-Delta area of Nigeria, there is the need to concentrate 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 effects on the environments (Abdulkareem et al., 2011). In this work, mathematical modelling that can be used to predict the quantity of heat radiation from gas flaring station will be developed. The developed model will be simulated and find interaction between various parameters such as distance, volume of gas flared, flared stack efficiency that influence the rate of heat radiation from gas flaring station. Mathematical modeling is a simplified image of processes taking place in a system. These could include heat propagation, concentration of dispersion of gases from combustion and generation of heat and propagation e.t.c. Models retain the most essential properties of the

actual process but presents them in mathematical forms. According to Luyben (1995)." Mathematical modeling is very much an art. It takes experience, practice and brain power to be good mathematical modelers". Mathematical model of a system must be sufficiently simple, easy to grasp and give a clear idea about all the qualitative aspects of the phenomenon of interest. On the other hand, it must be sufficiently accurate in bringing the quantitative aspects of the process. Simulation represent the application of modelling techniques to real system, thus enabling information on plant characteristics to be gained without either constructing or operating the full scale plant or system under consideration. Simulation methods come in two type viz. Digital simulation and Analogue simulation of these two types, Digital simulation which involve the use of codes and programme are more in use since they can be implemented on modern computer with exceptional speed (William, 1995)

Figure 1. Gas flaring station in the Niger-Delta area of Nigeria

1.1. Oil exploitation and climate change

Pollution is a term that defines any environmental state or manifestation which is harmful or unpleasant to life, it can also be defined as the introduction of natural and artificial particulate contaminants into the atmosphere (Cemak, 1985; Odigure, 1998). This can be caused due to man's failure to achieve control over the chemical, physical or biological consequence or side effects of his scientific industrial and social habit (Drake and Hubacek, 2007). Industrial source of pollution is as a result of release of hazardous waste and huge

mass of unclear gases and other airborne particles produced as by- products in process industries (Odigure, 1998). The degree of the increase of process industries is increasing drastically, this improvement has changed man's way of life remarkably, however the advantages derived have not being without a price which is basically the effect of pollution on the environment (Carvalho et al., 2005; Baroutian, 2006). Pollutants are emitted into the atmosphere as either gases or particles, and are eventually removed by natural self cleansing processes (Ajayi, 1999; Alameddine and El-Fadel, 2005). The waste mostly originates from the burning of fossil fuels and the processing of materials by industries (Abdulkareem et al., 2011). Other sources include waste from burning engines in cars, fuel use in domestic sectors, oil boom, gas flaring, agricultural processes, but of all these the process industries have been recognized as the major source of air pollutants. The self-cleansing ability of the atmosphere which involves dispersion and dilution, is used as a grant channel, is presently too small and cannot match up to the rate of introduction of pollutants into the atmosphere, this is due to meteorological influences (Held et al., 2005; Potocnik et al, 2007; Soylu, 2007). During the 20th century contamination of the environment as a result of human activities has risen drastically (Hussain et al., 2005; Abdulkareem et al, 2009). Pollution problem have risen in all industrialized areas as well as in various inland, coastal water and stretches of ocean (Appleby, 1992; Kinnee et al., 2004). The capacity of the biosphere to disperse, degrade and assimilate human waste is in serious question, waste due to human activities now overweigh natural forces of putting toxic elements into the atmosphere (Ufarana, 2004). From colloid chemistry atmospheric air belongs to the group of incoherent, coarse dispersal system. More specifically, it is a system of colloid particles dispersed in gas in which solid and liquid component can be found in a mixture of gases, with this knowledge the term "pure air" cannot be defined because that will depend on the content of the air expected. Stern (1962 – 1968) said the composition of the air found near the soil level (homosphere) composes of various amount of substances additional to its constant component, this additional component are the air pollutants, thereby making pure air never to be in existence (Ufarana, 2004, Onyiah, 2005). The activities of the oil companies in the Niger Delta area of Nigeria are the major sources of the environmental pollution in the country. The situation that makes the public to consider 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. 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). Gas flaring cause green house effect, thereby producing global warming and green house gases which include: water vapour, carbon dioxide, Methane, Nitrous oxide; Ozone, Carbon monoxide and Nitrogen oxide (Indriani, 2005; Nwaichi and Uzabona, 2011).

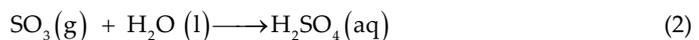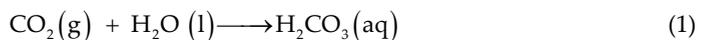### 1.1.1. Global warming and green house effect

Man's expanding activity has reached a level at which their effects are global in nature. The natural system i.e. the atmosphere, land and sea as well as life's and plants therein are clearly being disturbed (Cermak, 1985; Odigure, 1998) .It is obvious that some trace of CO_2, N_2O, CH_4 and O_3 gases have increased during the last century (Nigeria natural gas stategy, 2002; Nwaichi and Uzabona, 2011). In addition, other gases are being emitted that are not naturally part of the global eco-system, notably Chloro Fluoro Carbons (CFCS) (Odjugo, 2010; Abdulkareem and Odigure, 2010). These trace gases absorb and emit radiation and are thus able to influence the earth's climate. They are refereed to collectively as green house gases. The green house effect is described as a warming of the earth's surface and lower atmosphere that tends to intensify with an increase in atmospheric carbon dioxide. The atmosphere allows a large percentage of the rays of visible light from the sun to reach the earth's surface and heat it (Nyong, 2004; Odjugo, 2010). A part of this energy is radiated by the earth's surface in the form of long wave infrared radiation, much of which is absorbed by molecules of carbon dioxide and water vapour in the atmosphere and which is reflected back to the surface as heat (Abdulkareem and Odigure, 2002). This is roughly analogous to the effect produced by glass panes of a green house, which transmit sunlight in the visible range but hold heat. The trapping of this infrared radiation causes earth's surface and lower atmospheric layers to warm to a higher temperature than would otherwise be the case. Without this green house heating, the earth's average temperature would be only -73oC, even the ocean would be frozen under such conditions (Odjugo, 2010). Owing to the rise in atmospheric carbon dioxide caused by the modern industrial societies, widespread combustion of fossil fuels (coal, oil and natural gas), the green house effect on earth may be intensified. An increase in concentration of the atmospheric concentrations of other trace gases such as Chlorofluorocarbons (freons), nitrous oxide and methane due human activity may also aggravated greenhouse condition (Nwaichi and Uzabona, 2011).
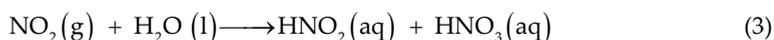
The realization that climate might change, as a result of emission of CO_2 into the atmosphere is not new. Arrhenius (1896) pointed out that burning of fossil fuel might cause an increase of atmospheric CO_2 and thereby changing the heat balance of the earth. Calendar (1938) convincingly showed that the atmospheric CO_2 concentration was increasing. The observation which began in 1958 has clearly shown that the concentration of CO_2 in the atmosphere has increased from about 315ppm to about343ppm in 1984 (Nyong, 2007). We know today that approximately, the amounts of CO_2 that have been emitted into the atmosphere by fossil fuel combustion and changing land use (deforestation and expanding agriculture) can related to the observed increase of atmospheric CO_2 to these human activities. Since a continued increase of atmospheric CO_2 concentration might lead to changes of global climate, it is essential to be able to project the likely future concentration that may occur due to various possible rate of CO_2 emissions .As far as the expected climatic change is concerned, it can be prognoses that a doubling of the CO_2 concentration would lead to an increase of the globally averaged temperature by 1.5-4.5 oC (Ufarana, 2004). The prediction that climate change due to human activities began with a prediction made by the Swedish Chemist, Svant Arrhenius, in 1896. Arrhenius took note of the industrial revolution

and realized that the amount of carbon dioxide being released into the atmosphere was increasing. He further believed that carbon dioxide concentrations will continue to increase as the world's consumption of fossil fuel particularly coal and fossil fuel increased even more rapidly. His understanding of the role of carbon dioxide in heating the earth led him to predict that if the atmospheric carbon dioxide is doubled, earth would become several degrees warmer (Ufarana, 2004).

1.1.2. Acid rain formation

Acid rain is commonly used to describe the deposition of acidic components in rain, snow, fog, dew or dry particles .(Ufarana, 2004). The primary sources are sulphur dioxide, carbon dioxide and oxide of oxides of nitrogen (Uyigue and Agho, 2007). A variety of industrial processes, such as the production of iron and steel, utility factories, oil producing companies are responsible for the emissions of obnoxious gases that resulted into acid rain. This report focused on the contribution of oil exploration and exploitation in the Niger-Delta area of Nigeria to the formation of acid rain. It has been reported that acid rain is one of the most discussed modes of environmental pollution in recent years (Odigure and Abdulkareem, 2001). This is caused by the considerable quantities of Sulphur dioxide and Nitrogen oxide released into the atmosphere as fossil fuel is burnt (SPDC Report, 1981). These pollutants combine with water vapour contained in the air to form dilute solution of sulphuric acid, which are subsequently washed out of the atmosphere by rain or other type of precipitation such as fog and snow (Thompson, 1991). The carbon (iv) oxide (CO_2) gas released during gas flaring also dissolves in water to form carbonic acid (H_2CO_3), the concentration of the gas in water depends on the extent of dissolution of gas in water (Abenege, 2004). Although, acid rain usually consists of relatively mild acids, they are sufficiently caustic to do great harm over time to certain natural ecosystems. Already there is much evidence that deposition of acid leads to lakes and stream acidification, stunted growth of flora while acid sensitive crops will die in affected areas (Abdulkareem, 2000). In cities, the corrosions of buildings and monuments are both exacerbated and accelerated (Odigure and Abdulkareem, 2001). To some extent acid rain has always been present in certain humid environment, originating from natural events as volcanic eruption, forest fires and even the bacterial decomposition of dead organism (Odigure and Abdulkareem, 2001). However, as the worldwide industrial revolution spread globally, the destructive capabilities of natural acid rain have been enhanced by human actions. The phenomenon of acid rain due to the dissolution of these acid gases in the atmospheric water in the sky so that it becomes acidic thereby leading to formation of rain with pH below 5.0 as shown in Equations 1-3 (Abdulkareem, 2000). Its effect is usually by its corrosion of rooftops, discoloration of paints on building, premature rusting of metallic object, damage to flora and fauna (Plant productive parts).

$$CO_2(g) \ + \ H_2O\ (l) \longrightarrow H_2CO_3(aq) \tag{1}$$

$$SO_3(g) \ + \ H_2O\ (l) \longrightarrow H_2SO_4(aq) \tag{2}$$

$$NO_2(g) + H_2O(l) \longrightarrow HNO_2(aq) + HNO_3(aq) \tag{3}$$

1.1.3. Ozone layer depletion

Increasing concentration of the synthetic chemicals known as Hallon (Bromine fluoro carbons) and Chlorine Fluoro Carbons (CFC'S) are known to enhance the breaking down of the ozone layer, allowing more of the ultraviolet rays to penetrate to the earth surface (Ifeanyichukwu, 2002, Abenege, 2004; Ufarana, 2004). Ultraviolet rays can break apart important biological molecules including Deoxyribonuclectic acid (DNA). Increased ultraviolet radiation can lead to greater incidence of skin cancer and immune deficiencies as well as decreased crop yield and reduced population of certain fish larvae Pluto Plankton and Zooplankton that are vital to the food chain. Increased ultraviolet radiation can also lead to smog and reduced the useful life of paints and plastics. Stratospheric ozone protects oxygen at lower altitude from being broken up by ultraviolet light and keeps most of those harmful rays from penetrating to the earth's surface (Abdulkareem, 2000) . Hallons are an industrial group of chemical that contains bromine, which reacts in a manner similar to chlorine by catalytically destroying ozone. Halons are used primarily in fire extinguishing foam. Chloro Fluoro Carbons (CFC'S) are compounds that consist of chlorine, fluorine and carbon, first introduced in the late 1920s, these gases have been used as coolant for refrigeration and air conditioners, propellant for aerosol sprays, agents for producing plastic foam and cleaners for electrical parts (Abdulkareem, 2000; Odjugo, 2011). CFC'S do not degrade easily in the troposphere as a result they raise into the stratosphere where they are broken down by ultraviolet light. The chlorine when liberated reacts with ozone to produce two molecules of oxygen. In the upper atmosphere, ultraviolet light breaks off a chlorine atom from a CFC'S molecule. The chlorine radicals attack ozone molecules and breaking it into an ordinary oxygen molecule and a molecule of chlorine monoxide, while the free oxygen radicals breaks up the chlorine monoxide as shown in Equations 4-7 (Abdulkareem, 2000). The freed chlorine radical is again available to repeat the process. Chlorine acts as catalyst and is unchanged during the process. Each chlorine atom can destroy as many as 10,000-ozone molecules before it returned to the troposphere.

$$CFCl_3 \rightarrow FCl_2 + Cl + C \tag{4}$$

$$Cl + O_3 \rightarrow ClO + O_2 \tag{5}$$

$$O_2 \rightarrow 2O \tag{6}$$

$$ClO + O \rightarrow Cl_2 + O_2 \tag{7}$$

1.2. Effect of heat radiation from 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 (Nyong et al., 2007). 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 (Odjugo, 2010). 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 (Abdulkareem et al., 2009). 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 (UNDP/World Bank, 2004). 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 (Uyigue and Agho, 2007). 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 heat radiation and elevation of temperature (Odigure et al, 2003). Typical gas flare in the Nigerian oil field are located at the ground level as shown in Fig 1 and surrounded by thick vegetation, farmland and villages huts 20-30m from the flare station (Odigure et al., 2003). The heat radiation from the flare station is a function of the flare temperature, gas flow rate and the geometrical design of flare stack (Odigure et al., 2003).

The combustion of gaseous hydrocarbons contained in the natural gas is an exothermic process, which result in the evolution of heat to the atmosphere (Abdulkareem et al., 2009). This endangers both the plant and animal life around the vicinity gas flaring stations. Although the mechanism of radiant energy transfer is not completely understood, however the associated phenomenon is explained in terms of dualistic theory (Abdulkareem and Odigure, 2002). This theory deals separately with the emission and reception of radiation and with its transmission, radiation is emitted and received in discrete particle called photon. The geometric relationships between emitting and receiving surfaces have been kept very simple by arranging that emitting surface sees only the receiving surfaces. In practice it is not possible for heat radiated to strike the receiver completely. This necessitated the introduction of geometrical factor to relate the radiant energy striking a surface to the total radiant energy emitted (Abdulkareem and Odigure, 2002). While the concept of heat as a pollutant may seem impossible on a cold winter day, it is important to note that at any time of the year, an increase in water temperature has effect on aquatic life (Odigure et al., 2003). Heat pollution is a consequence of the rising in energy demand by man's activities. For instance the power plants burns fossil fuel or nuclei fuel to provide the energy needed for industrial consumptions, they released considerable amounts of heat (Abdulkareem, 2000). The power plants that release these huge amounts of energy are located near bodies of water, which the plant used for heat dissipation purposes. Living things especially cold blooded animal i.e. fish are very sensitive to small change in the average temperature. It has

been reported that fish hatch its eggs before the hatching period due to change in water temperature. It may also prevent fish eggs from hatching at all (Abdulkareem, 2009; Odigure et al., 2003). In addition, a small rise in average temperature could produce a profound climatic change. Some experts' belief a small rise in temperature would cause the Greenland and Antarctic ice to melts, raising ocean levels and inundating large areas of land (Abdulkareem., 2009). The average worldwide temperature can be affected when the products of combustion such as carbon monoxide, water vapour and carbon dioxide are emitted in large quantities into the atmosphere (Tzimas et al., 2007). Although, solar energy on its way to the earth surface easily pass through the layers of carbon dioxide, some of the heat escaping through the earth will be absorbed by the increase amount of carbon emitted to the atmosphere by the process industries and releases back to the earth with negative impact on the soil (Abdulkareem and Odigure, 2002). For instace, the heat from gas flared falls on the soil thereby heating it up, increases in heat deposition on soil reduces diseases generally, it may not be suitable for some plants and crops to survive hence rendering such land unsuitable for cultivation (Aduku, 1997). There is therefore, a great physiological impact on crops planted in the vicinity of the gas flares station. It has been reported that there could be about 100% loss in yield of crops cultivated 200m away from the flares stations, 45% loss in yield of crops at 600m away and 10% loss in yield of crops cultivated 1000m away (Oyekunle, 199).

2. Development of mathematical modelling

The burning process of natural gas also referred to as combustion is described as a rapid oxidation or burning of substances with simultaneous evolution of heat. In the case of common fuels, the process is one of the chemical combinations with atmospheric oxygen to produce as the principal product. Gas flaring of produced gas i.e the process of burning-off surplus combustible vapours from a well, either as a means of disposal or as a safety measure to relieve well pressure - is the most significant source of air emissions from offshore oil and gas installations. Hence gas flaring activity in the Niger- Delta area, and the pollutants released to the atmosphere is causing a lot of damage to the area. It is on this basis that a mathematical model that can quantify the quantity of heat discharged from gas flaring stations into the environment will be developed. 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

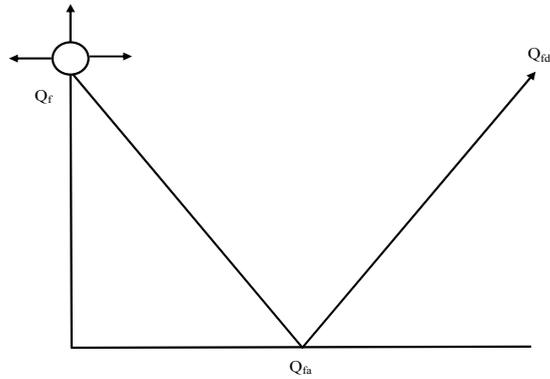Below is the schematic diagram of heat radiation in a flare station.

Figure 2. Schematic of heat radiation from gas flared station

Heat balance

Taking heat balance from Fig 2

$$Q_f = Q_{fd} + Q_{fa} \tag{8}$$

Where

- Q_f = heat from flare gases
- Q_{fa} = heat absorbed by earth from flare gas
- Q_{fd} = heat from flare reflected

From assumption (iii) i.e. heat from flares are used in vaporizing water, retained by the soil and the remaining reflected i.e.

$$Q_{fa} = Q_s + Q_v \tag{9}$$

Where

- Q_s = heat retained by soil
- Q_v = heat used in vapoursing water

Substituting equation (9) into (8) gives

$$Q_f = Q_{fd} + Q_s + Q_v \tag{10}$$

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

$$Q_{fd} = Q_f - Q_s - Q_v \tag{11}$$

Where

$$Q_s = M_s C_s \int_{T_{soil}}^{T_s} dT \tag{12}$$

From equation (12)

$$Q_s = M_s C_s [T_s - T_{soil}] \tag{13}$$

Where

- M_s = mass of soil
- C_s = specific heat capacity of soil
- T_s = temperature of flare gas
- T_{soil} = temperature of soil

$$Q_v = M_w C_w \int_{T_{soil}}^{T_s} dT + M_w \lambda_v \tag{14}$$

From equation (14)

$$Q_v = M_w C_w [T_s - T_{soil}] + M_w \lambda_v \tag{15}$$

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,

$$Q_c = \alpha Q_f (1 - a) \tag{16}$$

Where

α = absorptive factor which varies with distance, a = Alhedo constant, Q_c = fraction of the heat which strikes the receiving surface

Hence,

$$\alpha Q_f (1 - a) = M_w C_w (T_s - T_{soil}) + M_w \lambda_v + M_s C_s [T_s - T_{soil}] \tag{17}$$

Substituting equations (13), (15) and (17) into equation (11) gives

$$Q_{fd} = Q_f - [M_s C_s [T_s - T_{soil}] + M_w C_w [T_s - T_{soil}] + M_w \lambda_v] \tag{18}$$

Similarly, from Equations 11 and 16;

$$Q_{fd} = Q_f - \alpha Q_f (1 - a) \tag{19}$$

Rearrange Equation 19 to obtain

$$Q_{fd} = Q_f (1 - \alpha (1 - a)) \tag{20}$$

Evaluation of Q_f

Ufarana (2004) suggest that that the flame from is titled at 45°, hence

$$h_{fv} = L(\sin 45^o) = 0.707L \tag{21}$$

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

And L is the flame length

From Equation 21

$$L = \frac{h_{fv}}{0.707} \tag{22}$$

The vertical height vector of the flare stack (hfv) can also be calculated from (Ufarana, 2004)

$$h_{fv} = 0.0042Q_f{}^{0.478} \tag{23}$$

From Equations 22 and 23;

$$L = \frac{0.0042}{0.707}Q_f 0.478 \tag{24}$$

$$\therefore\ L = 0.00594Q_f{}^{0.478} \tag{25}$$

From Steward's correlating equation (Ufarana, 2004)

$$L = 0.8632Q_f{}^{0.4}N' \tag{26}$$

Where,

$$N' = \text{a combustion parameter} = \frac{\left(\dfrac{r + w\rho_a}{\rho}\right)^{0.4}}{[(NHV)^{0.4}(1-w)]} \tag{27}$$

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 (25) and (26) gives

$$0.00594Q_f{}^{0.478} = 0.8632Q_f{}^{0.4}\ N' \tag{28}$$

From Equation (28)

$$Q_f{}^{0.078} = 145.32N' \tag{29}$$

From Equation 27

$$N' = \frac{\left(\dfrac{r + \left(\dfrac{rC_pT_a\rho_a}{rC_pT_a + NHV}\right)}{\rho}\right)^{0.4}}{(NHV)^{0.4}\left(1 - \dfrac{rC_pT_a}{rC_pT_a + NHV}\right)} \tag{30}$$

Rearrange Equation 30 to obtain;

$$N' = \left(\frac{(rC_pT_a(r\rho + \rho_a) + r\rho NHV)^{0.4}}{\rho^{0.4}(NHV)^{1.4}}\right)(rC_pT_a + NHV)^{0.6} \tag{31}$$

Substituting Equation 31 into Equation 29 gives

$$Q_f^{0.078} = 145.32\left(\frac{(rC_pT_a(r\rho + \rho_a) + r\rho NHV)^{0.4}}{\rho^{0.4}(NHV)^{1.4}}\right)(rC_pT_a + NHV)^{0.6} \tag{32}$$

From Equation (32)

$$Q_f = \sqrt[0.078]{145.32\left(\frac{(rC_pT_a(r\rho + \rho_a) + r\rho NHV)^{0.4}}{\rho^{0.4}(NHV)^{1.4}}\right)(rC_pT_a + NHV)^{0.6}} \tag{33}$$

Substituting Equation 33 into Equation 20 gives

$$Q_{fd} = \left(\sqrt[0.078]{145.32\left(\frac{(rC_pT_a(r\rho + \rho_a) + r\rho NHV)^{0.4}}{\rho^{0.4}(NHV)^{1.4}}\right)(rC_pT_a + NHV)^{0.6}}\right) \times \\ (1 - \alpha(l - a)) \tag{34}$$

Relationship between net heating value and distance from flare point is given as (Ufarana, 2004)

$$NHV = \frac{mc\theta}{x} \tag{35}$$

Where m = mass of flared gas, c = heat capacity of flared gas, θ = temperature of flared gas, x = distance

Substituting Equation 35 into Equation 34 to obtain

$$Q_{fd} = \left({}_{0.078}\sqrt{145.32\left(\frac{\left(rC_pT_ax(r\rho + \rho_a) + \rho mc\theta\right)^{0.4}}{\rho^{0.4}(mc\theta)^{1.4}}\right)}(rC_pT_a + mc\theta)^{0.6}x^{0.4}\right) \times$$

(36)

$$(1 - \alpha(l - a))$$
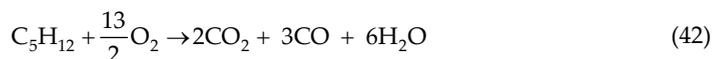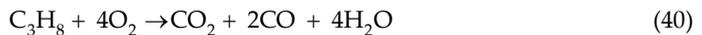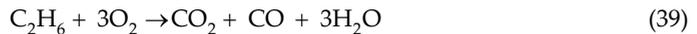
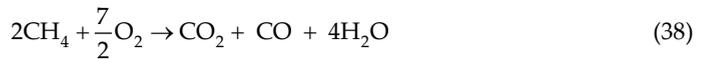But

$$m = \rho_T V_T$$

(37)

- Where m = mass of flared gas
- V = volume of flared gas
- ρ_T = density of gas produced by gas flaring
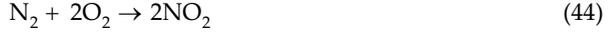- V_T = volume of gas produced by gas flaring which can be calculated as follows:

The volume of obnoxious gases produced such as CO, CO_2, NO_2, SO_2 and THC when Vm^3 of gas is flared was estimated on the assumption that combustion of the associated gas is incomplete in air as shown in Equations 38-44. The calculation was also based on the compositions of associated gas in crude oil at the flare stations (Table 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

Table 1. Component of gas flared (Abdulkareem, 2000)

Evaluation of volume of gas flared was estimated on the assumption that combustion is incomplete in air with the following reactions take place during the process of combustion.

$$2CH_4 + \frac{7}{2}O_2 \rightarrow CO_2 + CO + 4H_2O$$

(38)

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

(39)

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

(40)

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

(41)

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

(42)

$$H_2S + O_2 \rightarrow SO_2 + H_2 \tag{43}$$

$$N_2 + 2O_2 \rightarrow 2NO_2 \tag{44}$$

Basis: $1m^3$ of flared gas

Let S_E = stack energy

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

$$= 0.00845S_E + 0.1235S_E + 0.000003S_E + 0.00004S_E + 0.99 - 0.00990S_E =$$
$$= (0.99 + 0.0109074S_E)m^3 = V_T \tag{45}$$

Equation (45) represents the total volume of gas produced by flaring $1m^3$ of gas. But when Vm^3 of gas is flared equation (45) becomes

$$(0.99 + 0.0109074S_E)Vm^3 = V_T \tag{46}$$

From Equation 37 i.e. $m = \rho_T V_T$

Substituting Equation (46) into Equation (37) gives

$$m = \rho_T(0.99 + 0.0109074S_E)V \tag{47}$$

Substituting Equation 47 into Equation 36 gives

$$Q_{fd} = 0.078 \sqrt{145.32 \left(\frac{[rC_pT_ax(r\rho + \rho_a) + \rho\rho_T(0.99 + 0.0109074S_E)VC\theta]^{0.4}}{\rho^{0.4}\left(\rho_T(0.99 + 0.0109074S_E)VC\theta\right)^{1.4}} \right)} $$
$$\left(rxC_pT_a + \rho_T(0.99 + 0.0109074S_E)VC\theta\right)^{0.6} x^{0.4}$$

$$(1 - \alpha(1 - a)) \tag{48}$$

Where $\theta = T_s - T_a$

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

Equation (48) is the model equation for the heat reflected due to gas flaring.

3. Results and discussion of results

Environmental pollution has transcended natural boundaries; stratospheric ozone depletion, global warming, the green house effect, deforestation, acid train and mega disaster are some of the various environmental problems attributed to pollution. The potential effects of global pollution have necessitated global cooperation in other to secure and maintain a live able global environment (Odjugo, 2010). It has been reported that pollutants emitted from one

country can easily cross political boundaries. People are beginning to recognize that pollutants can affect not just a region but the entire planets. Modern industrial society creates far more carbon (IV) oxide (CO_2) that what the planet vegetation can consume (Odigure and Abdulkareem, 2001). As the excess CO_2 rises into the atmosphere, it acts as absorptive body, which trap heat reflected from the earth surface. Scientists accept that green house effect from increased level of CO_2 and other heat trapping gases eventually will cause an increase in global temperature. Some predicted that the temperature will rise significantly within the next century and that global pattern could be drastically disrupted. Air pollution is not restricted to outdoor air, although relatively little attention is given to the hazards of many substances found in indoor air most especially in the developing nations where there is no proper regulation in place to combat air pollution. But it is however well established that people may spend as much as 80-90% of their time indoor. The sources of indoor pollution are different for developing and industrialized country (Odigure and Abdulkareem, 2001). In developing countries, indoor pollution comes mainly from using biomass fuels (Wood, agricultural waste, dung etc.) for cooking and heating. The majority of the world's population depends on biomass for most of their energy supply. It is estimated that as many as 400-500 million people mainly in the rural area of developing countries and primarily women and children may be adversely affected by indoor pollution (FEPA Report, 1998). The fuel is burnt inefficiently in rooms that poorly ventilated. Biomass smoke contains numerous substances, the most hazardous of which include suspended particulate matter, nitrogen dioxide, carbon dioxide and sulphur dioxide (Gwendolyn et al, 1993). It also releases a number of aldehyde. While the key indoor pollutants in an industrialized countries are nitrogen dioxide, carbon monoxide, radon (from building material), formaldehyde (from insulator, asbestos, mercury, manmade fibers etc. Also polluting the environment is the heat radiated as result of these indoor activities and process industries. The released may be harmful to plant and animal. In Nigerian context, gas flaring from the oil exploitation and exploration in the Niger-Delta area of the country has been considered as the major sources of environmental pollution. Every day 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 (Oni and Oyewo, 2011). Hence, gas flaring is not only wastes of valuable resources, but is also a major cause of environment pollution in the Niger-Delta, where most of Nigeria's oil output is produced. Nigeria has a population of over 170million people and an abundance of natural resources especially hydrocarbons. The Nigerian economy is largely dependent on its oil sector which supplies 95% of its foreign earnings. 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 problematic. The public considers the oil producing companies operating in the Niger-Delta oil fields responsible as major environmental pollutants 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. It is therefore, on this ground that a mathematical model that can quantify the amount of heat radiation from a flare stack is developed in this work. The model will assist in estimating the quantity of heat migration from gas flaring as a function of flare temperature, gas flow rate and geometric design (Efficiency) of the flare stack. Data gathered on the rate of flaring of gas and the measured quantities of heat radiation are presented in Tables 1 and 2. While the simulated results at different conditions for a period of one year for gas flare stations 1 and 2 are presented in Figs. 2-7

Table 2 present the average volume of gas flared from two flare stations per month for a period of one year. Results as presented indicate non uniformity in the volume of gas flared by the flare station per months. For instance, the volume of gas flared in station 1 for the month of May was 2.03m³/sec while the volume of gas flared in the same station in the month of June was 1.65m³/sec. Results also reveal variation in the rate of gas flaring by the two stations investigated, with average rate of gas flaring by station 2 higher than that of station 1. The variation in the rate of gas flaring as presented can be attributing to the variation in the rate of production of crude by the two stations. The crude oil obtained from wells is a mixture of crude oil itself, water and natural gas. At the flow stations, the components are separated and the gas that not be contained is flared. Hence when the rate of crude oil produced increases, the quantity of gas flared will also increases.

	Volume of gas flare (m³/s)	
Months	Station 1	Station 2
Jan	1.78	2.79
Feb	2.10	3.16
Mar	1.52	2.78
April	1.56	3.21
May	2.03	2.91
June	1.65	2.66
July	1.74	2.64
Aug	1.39	2.87
Sept	1.92	3.01
Oct	1.30	2.56
Nov	0.99	2.81
Dec	1.75	2.97

Table 2. Flow rate of gas flared per month

Presesnted in Table 3 are the measured values of heat radiation per month by station 1 for a period of eight months. The measured values showed that 0.805×10^{-3} kW/m² of heat was radiated at a distance of 100m for the month January, while 0.050×10^{-3} kW/m² of heat was radiated at the same distance for the month of February. Values of heat radiation presented in Table 3 do not show any distribution pattern with seasons. The un-pattern nature of heat radiation per season could be attributed to the volume of gas flared, distances from flared

point and wind speed. However, the measured heat radiation to large extent conforms to the physical law of pollutant dispersion from the generating sources.

Months	Heat Radiation (kW/m²) ×10⁻³							
	Jan	Feb	Mar	April	May	June	Sept	Dec
Distances (m)								
100	0.805	0.553	0.050	3.016	2.672	2.735	1.527	0.837
150	0.716	0.514	0.076	2.465	2.429	1.994	1.668	0.725
200	0.620	0.440	0.075	1.010	3.034	1.697	2.708	0.620
250	0.330	0.332	0.075	3.916	2.175	1.682	2.262	0.522
300	0.319	0373	0.094	0.312	1.675	1.520	1.929	0.457
500	0.558	0.237	0.091	0.979	1.262	1.519	1.849	0.305

Table 3. Heat radiation from gas flaring station 1

Simulation of the model is the use of computer code to show the operation and behavior of the system. The model equation developed for the heat radiation from gas flaring was simulated using Q-basic programme. The results obtained are presented in Figs 3-8. The simulated results values are obtained at various distances ranging from 25m to 1500m for different volume of gas flared and at different stack efficiencies of 65%, 75% and 85%. The choice of these 3 stack is as favoured by the world bank report that flare stack efficiency in the flare station of Niger-Delta area of Nigeria is 75%. It can be seen from the simulation results presented that the heat radiation from gas flaring for different stations increases with increase in volume of gas flared and stack efficiency, while the quantity of heat radiated reduces with increase in distance from the flare point. For instance in the month of May at a distance of 100m the quantity of heat radiated is 0.00262287 kW/m² while at a distance of 200m the quantity of heat radiated is 0.0023729 kW/m² for station 1. Results as presented also indicate that at a stack efficiency of 64% in the month of May, the quantity of heat radiated at a distance of 100m is 0.00262287 kW/m², while for that same month at the same distance in the same station when the stack efficiency is 74%, the quantity of heat radiated is 0.00279044 kW/m². Simulation results presented also indicates that the highest quantities of heat is radiated in the month of June for station1 and this as a result of the fact that highest amount of gas flared in this station during this month. Results as presented in Figs for station2 indicates same pattern of results as obtained in station1. It could be observed from the experimental and simulated results that the habitants of the Niger-Delta area of Nigeria are exposed to serious environmental risk based on the quantities of heat released into the environment from the gas flare stations. Results obtained support the claims by the researchers that the fire form gas flaring stations generate constant heat, which in turn evaporate water produced around the flare point, thus increasing the salinity of the pool water. There is also an evidence including the observation by the local farmers that the flare is considerably diminishes the value of agriculture productivity. Other observation made in the Niger-Delta area as a negative consequence of heat radiation from gas flaring is that the game animals were scared away by the fire.

Comparison of experimental results with simulated results showed that there is variation between them. The variation between experimental and modeling simulation results could be attributed to the following factors.

1. The un-patterned nature of the experimental data, which could be attributed to the fact that the weather conditions and rate of rainfall are not constant throughout the season. As a result, the heat will accumulate in the air during no rain period. However, when it rains part of the accumulated heat pollutant will be washed away

2. Experimental values are a measure of the extent of atmospheric pollution because of possibility of accumulation as stated above. While the simulation results are an instantaneous value i.e. it measured the possible amount of heat that could be released during flaring at a given time.

3. Atmospheric conditions such as wind speed, humidity, temperature e.t.c affect the dispersion and dilution of heat radiation from flare stack as a function distance.

4. The variation in experimental and simulations values could also be attributed to some assumption made at the initial stage of the modeling, such as wind speed, weather condition, volume of gas flared e.t.c. These assumptions may not conform to prevailing atmospheric condition.

Despite the variation between the experimental and simulated results, the dispersion pattern of the obtained values from experimental and simulation showed that the model and experimental results to a large extent conforms to the modified physical law proposed by (Gwendolyn, 1993).
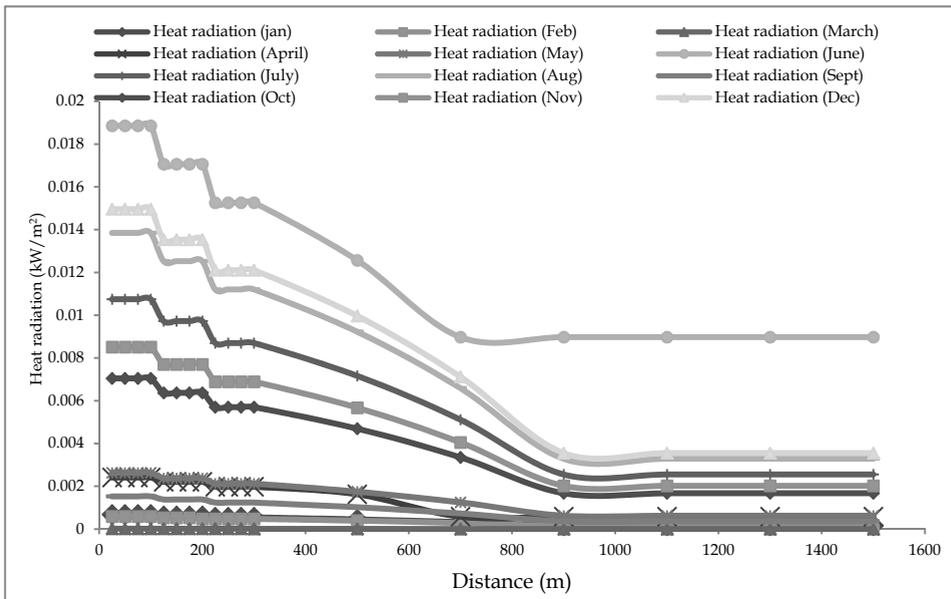

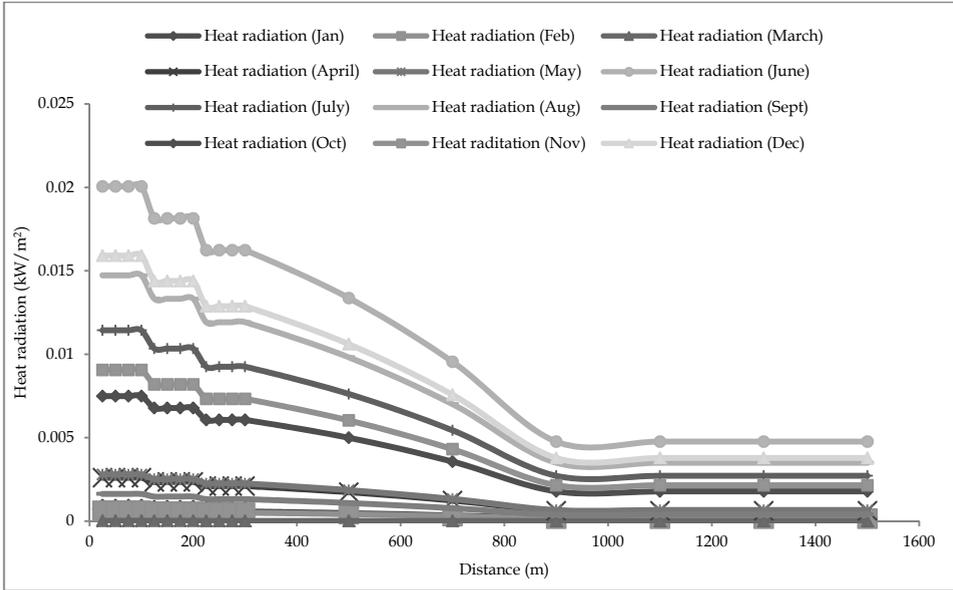**Figure 3.** Heat radiation from gas flaring (Station 1) with a stack efficiency of 65%

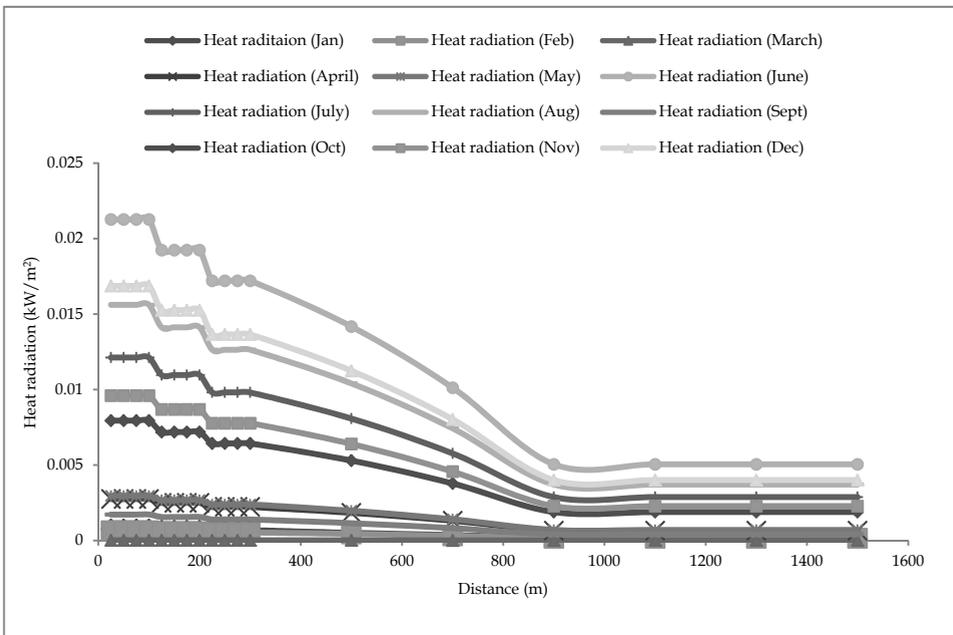**Figure 4.** Heat radiation from gas flaring (Station 1) with a stack efficiency of 75%

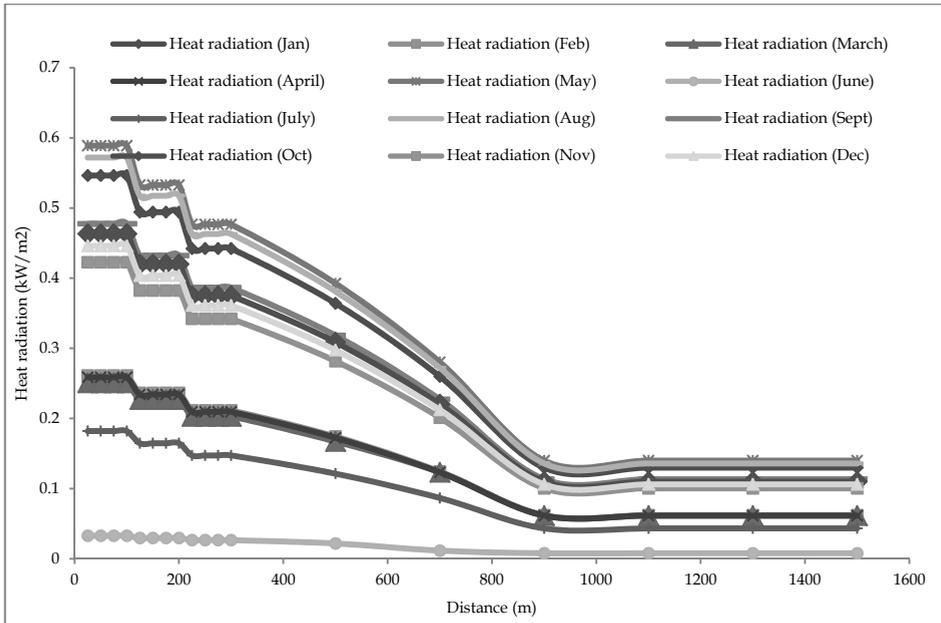**Figure 5.** Heat radiation from gas flaring (Station 1) with a stack efficiency of 85%

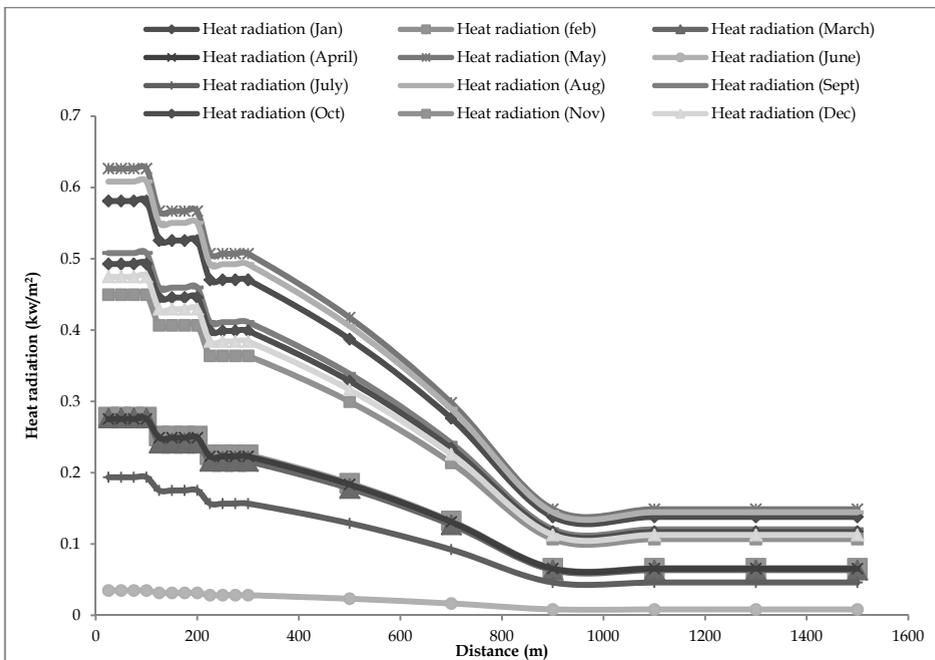**Figure 6.** Heat radiation from gas flaring (Station 2) with a stack efficiency of 65%

Figure 7. Heat radiation from gas flaring (Station 2) with a stack efficiency of 75%
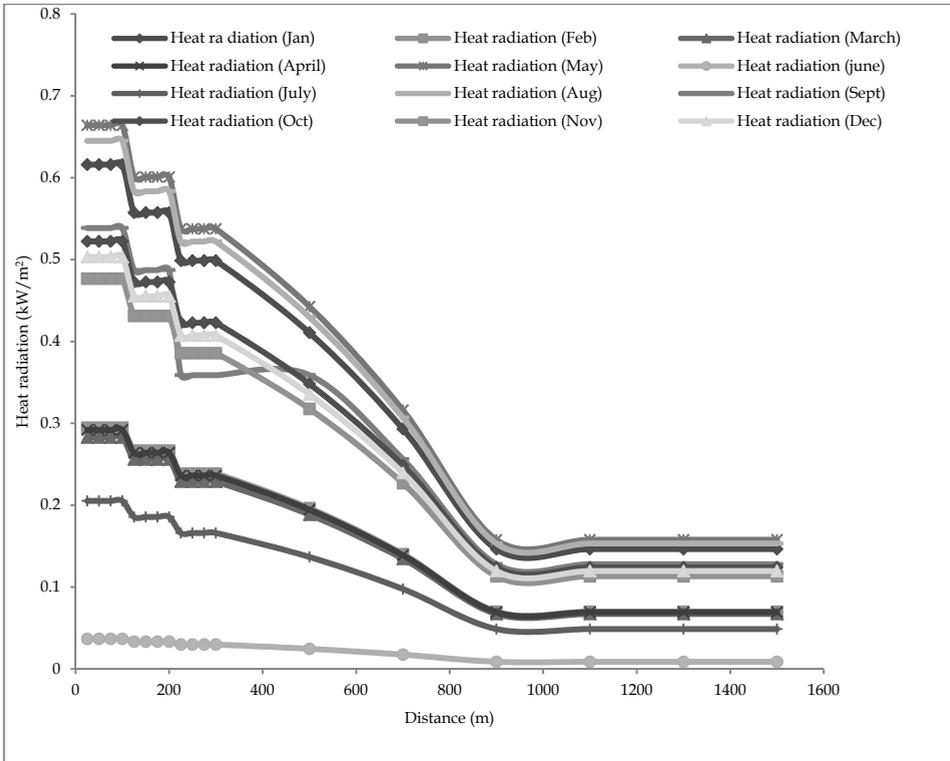
Figure 8. Heat radiation from gas flaring (Station 2) with a stack efficiency of 85%

4. Conclusion

Environmental pollution due to heat radiation from gas flaring stations in the Niger-Delta area of Nigeria has been identified as one of the major causes of strives, demonstration and sometimes-violent protest between the oil exploration companies and habitants of Niger-Delta area of Nigeria. Experimental analysis of heat radiation from gas flaring has been conducted. Attempt at modeling heat radiation from flare station using q basic program is hereby presented. It can be inferred from the simulation results of the developed model that volume of gas flared considerably affects the quantity of heat radiation from gas flaring in a direct proportionate manner. Also influence the heat radiation from gas is the distances of measurement from the point of flare, as the distance increases the quantity of heat radiated decreases. It can be inferred from the results that the effect of heat radiated will be felt mostly felt at distances of 25-100m within the point if flare. The result also clearly show that show that continuous gas flaring irrespective of the quality deposited in the immediate environment will in the long run lead to change in the physicochemical properties of environment due to the quantity of heat radiated. From this research, the following conclusions can be deduced:

1. It was observed that the result of simulation of model developed based on the modified principles of pollutants dispersion agreed with the experimental results.
2. The dispersion pattern of heat radiation based on the simulation results showed that the extent of spread heat from the flare point is dependent on nearness to source of flaring, volume of gas flared and stacks efficiency.
3. Model equation that best represents pollutant dispersion pattern is:

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

$$(1 - \alpha(l - a))$$

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6. References

Abdulakreem, A. S. & Odigure, J.O. (2002). Radiative Heat Evaluation from Gas Flaring By Computer Simulation. Journal of Association for the advancement of Modelling and simulation in enterprises, Lyon France. Vol.71, No 2, pp 19 – 35, ISSN 0761 – 2516.

Abdulkareem A.S. (2000). Mathematical modelling of pollutant migration from gas flaring in the Niger Delta Area. MsC thesis, Department of Chemical Engineering, Federal University of Technology, Minna. Nigeria (unpublished), 1-85.

Abdulkareem, A. S. (2005). Evaluation of ground level concentration of pollutant due to gas flaring by computer simulation: A case study of Niger – Delta area of Nigeria. Leonardo Electronic Journal of Practices and Technologies, Technical University of Cluj - Napoca Romania. Issue 6, pp 29 – 42, ISSN 1583 - 1078.

Abdulkareem, A. S.(2005). Urban Air Pollution Evaluation by Computer Simulation: A Case study of Petroleum Refining Company, Nigeria. Leonardo Journal of Science Technical University of Cluj - Napoca Romania. Issue 6, pp 17 – 28, ISSN: 1583 - 0233.

Abdulkareem, A.S & Odigure, J.O. (2006). Deterministic Model for Noise Dispersion from gas Flaring: A case study of Niger – Delta area of Nigeria. Journal of Chemical and Biochemical Engineering, Croatia Q 20, No 2, pp 139 – 146, ISSN 0352 – 9568.

Abdulkareem, A.S,; Odigure, J.O & Abenege, S (2010): Predictive model for pollutant dispersion from gas flaring: A case study of oil producing area in Nigeria. Journal of energy sources, Part A, 1004-1015. ISSN 1556-7036.

Abdulkareem, A.S. & Odigure. J.O. (2010): Economic Benefit of Natural Gas Utilization in Nigeria: A case study of Food Processing Industry. Journal of Energy Source Part B, Vol 5 Pp 106-114.

Abdulkareem, A.S.; Idibie, C.A.; Afolabi, A.S.; Pienaar, H.C.vZ. & Iyuke S.E. (2010): Kinetics of sulphonation of polystyrene butadiene rubber in sulphuric acid medium. Journal of International Review of Chemical Engineering, vol. 2, No7, pp 832-839, ISSN 2035-1755

Abowei, M.F.N.; Susu, A.A & Onyeme, J.O (1997). Oil spill in marine enviroment. CJC press (Nigeria) ltd, Lagos, Nigeria.1-50.

Adeniyi, O.D.; Kovo, A.S; Abdulkareem. A.S & Chukwudozie. C. (2007): Ethanol Fuel Production from Cassava as a Substitute for Gasoline. Journal of Dispersion and Technology, vol. 28, No4, pp 501-504, ISSN 0193-2691.

Aghalino, S.O & Eyinal, B (2009). Oil exploitation and marine pollution: Evidence from Niger-Delta, Nigeria. Journal of human ecology, vol.28(3), 177-182.

Ajayi, O.M (1999): Impact of gas flaring on the Niger-Delta Area: A case study of Port-Harcourt. B.Eng degree project, department of Chemical Enginnering, Federal University of Technology, Minn. Nigeria (unpublished) 10-26.

Akpan, S (2009). The production and utilisation of natural gas resources in Nigeria: A review. Proceedings of annual international conference and exhibition of the Nigerian Society of Petroleum Engineers, Abuja, Nigeria.

Alakpodia, I.J (1980): The effect of gas flaring on the microclimate and adjacent vegetation in Isoko area. Master of Science thesis, University of Lagos, Nigeria (unpublished), 1-50.

Alameddine, I & El-Fadel, M (2005). Stack emission from desalination plant: A parametric senstivity analysis for exposure assessment. Journal of desalination, vol. 177, 15-29.

Baroutian, S.; Mohebbi, A & Goharrizi, S.A (2006). Measuring and modelling particulate dispersion: A case study of Kerman cement plant. Journal of hazrdous materials, vol. A36, 468-474.

Carvalho, J.C& De Vihema, T.M.B (2005): Pollutant dispersion simulation fro low wind speed condition by the ILS method. Journal of atmospheric enviroment, vol.39, 6182-6288.

Cermark, J.E (1985): Physical modeling of urban air pollutant transport. Journal of wind and industrial aerodynamics, vol.59, 51-67.

Chimaroke, A.C (2004): Urban air pollution by computer simulation. B.Eng degree project, department of Chemical Enginnering, Federal University of Technology, Minn. Nigeria (unpublished) 1-56.

Davidson, O.R (1998). The climate convetion and Kyoto agreements: Opprotunities for Africa. Proceedings of an international conference on enviroment, Elephant Hills, Victoria Falls. Zimbabwe.

Davies, S & Ebbe, K (1995). Traditional knowledge and sustainable development. Proceedings of international conference on enviromentally suistainable development, world bank, Washigton, DC.

Drake, B & Hubacek, K (2007). What to expect from greater geographic dispersion of wind farms?-A risk portfolio approach. Journal of energy policy, vol.35, 3999-4008.

Eludinni, O.I (2004): A review of eceonomic benefits of natural gas utilization in Nigeria. B.Eng degree project, department of Chemical Enginnering, Federal University of Technology, Minn. Nigeria (unpublished), 1-51.

Global gas flaring reduction initiative (2002). Report on consultaion with stakeholders, world bank group on collaboration with goverment of Norway. 27-30.

Ifeayichukwu, G. P (2001). Modelin of air pollution in industrial cities: Case study of Lagos, Nigeria, B.Eng degree project, department of Chemical Enginnering, Federal University of Technology, Minn. Nigeria (unpublished) 1-60.

Ikelegbe, O.O (1999). Pollution in Nigeria: Cause effect and control. Proceddings of Nigerian Geographical Association conference, Minna, Niger State, Nigeria. 18-22.

Indriani, G (2005). Gas flaring reduction in the indonesian oil and gas sector –Technical and economic potential of clean development mechanism (CDM) projects. Hamburg instituite of international economics, report 253, 1-141. ISSN 0179-2253.

Janes, J.; Armstrong, K,; Shirvill, L,; Emannuel, G & Monoplis, J(2000). Flaring & venting in the oil & gas exploration & production industry: An overview of purpose, quantities, issues, practices and trends. International association of oil & gas producers, report no:2.79/288, 1-18.

Joint UNDP/World bank energy programme sector management programme (ESMAP). Strategic gas plan for Nigeria, February, 2004.

Kinee, E.J.; Touma, J.S.; Mason, R.; Therman, J.; Belder, A.; Bailey, C & Cook, R (2004). Allocation of on road mobile emissions to road segments for air toxics modelling in an urban area. Journal of transportation research, partB9, 139-150.

Luyben, W.L (1999). Process modeling, simulation and control for chemical engineers. 2nd edition, McGraw-Hill, Singapore. 15-91.

Nigerian natural gas stratergy under supervison of teh world bank (2002). IPA Energy consulting and Co. 12-25.

Nwaichi, E.O & Uzazobona, M.A (2011). Estimation of CO_2 level due to gas flaring in the Niger-Delta. Research journal of enviromental sciences, vol. 5(6), 565-572. ISSN 1819-3412.

Nyelong, P.N (2004). Global warming and global water. Journal of energy and enviroment, vol. 17 (1), 79-90.

Nyong, A.; Adesina, F & Osman Elasha, B (2007). The value of indigeneous knowledge in climate change mitigation and adaptation strategies in the African Sahel. Journal of mitigation, adaptation and startegtic global change, vol.12, 787-789.

Odigure, J. O & Abdulkareem, A. S. (2001). Modelling of Pollutant's migration from gas flaring: A case study of Niger – Delta area of Nigeria. Journal of Association for the advancement of Modelling and simulation in enterprises, Lyon France. Vol.62, No 3, p 57 – 68, ISSN 0761 – 2524.

Odigure, J. O.; Abdulkareem, A.S. & O.D Adeniyi, O.D (2003). Computer simulation of soil temperature due to heat radiation from gas flaring. Association for the advancement of Modelling and simulation in enterprises, Lyon France. Vol. 72, No 6, pp 1 – 10, ISSN 1259 – 5969.

Odigure, J.O.; Abdulkareem, A.S& Adeniyi, O.D (2004): Mathematical modelling and computer simulation of noise radiation by generator. Assumption university journal of technology, vol 7(3), 111-119., ISSN 1513-0886.

Odjugo, A.O.P (2009). Quantfying the cost of climate change impact in Nigeria: Emphsis on wind and rainstorms. Journal of humna ecology, vol.28 (2), 93-101.

Odjugo, A.O.P (2010). Regional evidence of climate change in Nigeria. Journal of geography and regional planning, vol. 3(6), 142-150. ISSN 2070-1845.

Odjugo, A.O.P (2011). Climate change and global warming. The Nigeria perspective. Journal of suistainable development and enviromental protection, vol.1(1), 1-12.

Olukoga, E.A (2002). Natural gas as a vehicular fuel. Proceedings of Nigeria gas association, international gas conference exhibition, Abuja, Nigeria. 6.

Oni, I.S & Oyewo, A.M (2011). Gas flaring, transportation and susitanable energy development in the Niger-Delta, Nigeria. Journal of human ecology, vol. 33(1), 21-28.

Onyiah, I.M (2005): Modificcation and verification of Milton equation for measuring gaseous pollutant concentration. Post graduate diploma thesis, Department of Chemical Engineering , Federal University of Technology, Minna, Nigeria (unpublished), 1-63.

Oyekunle, L.O (1999): Effect of gas flaring in Niger-Delta area. Proceddings of Nigerian Society of Chemical Engineers, Port-Harcourt, Nigeria. 13.

Potocnik, P.; Thaler, M.; Gavekar, E.; Grabec, I & Puredoz, A (2007). Forecasting risks of natural gas consumption in Slovenia. Journal of energy policy, vol.35, 4271-4282.

Reymond, M (2007). European key issues concerning natural gas: Development and vulnerability. Journal of energy policy, vol. 35, 4169-4176, ISSN 0301-4215

Soylu, S (2007). Estimation of Turkish road transport emssions. Journal of energy policy, vol.35, 4088-4094, ISSN 0301-4215

Tolulope, O.A (2004). Exploration and enviromental degredation: The Nigerian experience. Journal of enviromental informatics archive, vol.2, 387-393.

Tsimas, E.; Mercier, A.; Cormos, C.C & Peteves, S.D (2007). Trade-off emissions of acid gas pollutants and of carbon dioxide in fossil fuel power plant with carbon captive. Journal of energy policy, vol.35. 3991-3997, ISSN 0301-4215

Udeta, M.E.M.; Burani, G.E.; Maure, J.O.A & Oliva, R.C (2007). Economics of secondary energy from GTL regarding natural gas reservoirs of Bolivia. Journal of energy policy, vol.35, 4095-4106, ISSN 0301-4215

Ufarana, O.R (2004). Dispersion of heat radiation from gas flaring in Niger-Delta. B.Eng degree project, department of Chemical Enginnering, Federal University of Technology, Minn. Nigeria (unpublished), 1-85.

Uyigue, E & Agu, M (2007). Coping with climate change and enviromental degradation in the Niger Delta of Southern Nigeria. Report of community research and development center (CREDC), Lagos, Nigeria, 1-31.

Yassin, M.F.; Kato, S.; Ooka, R.; Takahashi, T & Kouno, R (2005). Field and wind tunnel study of pollutant dispersion in a built area under various meterological conditions. Journal of wind engineering and industrial aerodynamic, vol. 93: 361-382.