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Computer Simulation of Soil Temperature due to Heat Radiation from Gas Flaring

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Abstract

Exploitation of Nigeria abundant natural resources of crude oil and natural gas has lead to wastage of the gas through flaring, the resultant effect is the deterioration of the environment which is also witnessed in the increasing heat content of the soil mantle in areas closer to the flare station. This paper proposes a mathematical model, which can be used to predict the soil temperature as a result of heat released by flaring gases and the sun. The results of simulation showed a remarkable agreement with experimental result of soil temperature taken at various distances and that the soil temperature depends on the volume of gas being flared together with the absorptivity of the soil in a given area.

Keywords: Gas flaring, soil temperature, heat radiation and environmental pollution.

1. Introduction

The petroleum industry is undoubtedly the main stay of the Nigeria economy and has led to a considerable economic growth in the country. The Niger-Delta oil fields of Nigeria covers about 70,000 square kilometers and is one of the world's largest wetlands, which houses Nigeria's proven gas reserves, estimated to be 120 trillion cubic feet (Oguejiofor, 2000). However, while the exploitation and exploration of oil has created some fortunes and contributed positively to the socio-economic and technological advancement of Nigeria as a whole, the accompanying socio-economic and ecological fallouts remain grievous. The public considers the oil-producing companies operating in the Niger-Delta oil fields responsible for polluting the environment by way of relentless flaring and venting of gas in the environment, oil spillages, site clearing deforestation and destruction of flora and fauna and consequence disturbances of the ecosystem in the 70,000 square kilometers Niger-Delta wetland.

With respect to the gas flaring, its effect on vegetation, health and the microclimate are equally searing. Apart from the deafening howl of the raging fire at gas flare sites, the thick smoke that bellows into the sky causes acid rain, which eventually poisons the rivers and lakes thence killing aquatic organisms. It has been shown that gas flares generate tremendous heat, which is felt over an average radius of 0.5 kilometers thereby causing thermal pollution (Ikelegbe, 1993). It has also been observed that in gas flare sites in Isoko land, at an average distance of 43.8m from gas flare sites, temperature could be as high as 40°C (Alakpodia, 1980), and indeed the general appearance of the vegetation around the sites are pointers to the fact that gas flares have had adverse effects on the soil with the resultant pale and malnourished appearance of the vegetation.

1.1 Heat Effect On Soil

The soil mantle of the earth is indispensable for the maintenance of plant life, affording mechanical support supplying nutrients and water. Also the soil constitutes a major storage location for heat, acting as a sink for energy during the day and as source to the surface at night. Soil temperature is one of the most critical factors that influence important physical, chemical and biological processes in soil and plants. Plant species however vary widely depending on the soil temperature on which they grow. Bacterial growth and plant production both are temperature dependent. The same is true for the following processes, organic matter decomposition and materialization, and microbial processes such as biodegrading of pesticides and other organic chemicals. Their intensity of change varies with temperature (Jury et. al, 1991 and Adeniyi, 2001). Soil temperature affects plant growth first during seed germination. Although seeds of different plants vary in their ability to germinate at low temperature, all species show a marked decrease in germination rate in soils with low surface temperature (Russell, 1973). Plant growth after germination is also influenced by soil temperature. Metabolically regulated plant processes, such as water and nutrient update, can diminish below optimum rates at both low and high temperatures (Allmaras et al, 1964, Brady, 1990).

Heat from gas flare coupled with solar radiation falls on the soil whereby heating it up. Though increased heat content of the soil helps to reduce vegetables and fruits diseases and insects attack generally, it may not be suitable for some plants and crops. Hence heat could render such lands unsuitable for cultivation of some economic plants (Alakpodia, 1980).

2. Mathematical Modeling Of Soil Temperature

The following assumptions were made in the development of the mathematical equations:

Heat from flare is absorbed by the soil, part is used to vaporize water and the rest is reflected back; the area is a tropical forest; heat from the sun is used in vaporizing water, retained by the soil and the remaining reflected; the area is assumed to be a bed of soil i.e. soil of constant heat capacity; the intensity of the sun is uniform for a given area at a given time; combustion is complete in air and equal volume of gases is flared by all stations.

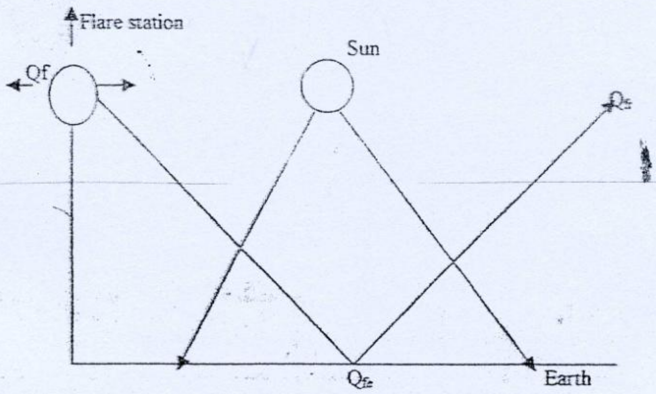

Figure 1: Schematic diagram of heat radiation in a flare station (Odigure and Abdulkareem, 2000).

During gas flaring, there is the release of large quantities of CO_2 than other gases such as those of sulphur and nitrogen oxides, which are in minute quantities because their content in associated gas being flared is small. The total hydrocarbon content of associated gas is about 92-95%. The composition of major hydrocarbon is given in Table 1 (Abdulkareem, 2000).

Table 1: The composition of major hydrocarbon

Composition	CH_4	C_2H_6	C_3H_8	C_4H_{10}	C_5H_{12}	Others
%Mass	>43	>15	20	5	9	<1

From the assumption that combustion is complete in air, the amount of CO_2 released by burning 1 kg of associated gas can be calculated from the stiochiometry as follows:

$CH_4 + O_2 \rightarrow CO_2 + 2H_2O$ 1

$C_2H_6 + 7/2O_2 \rightarrow 2CO_2 + 3H_2O$ 2

$C_3H_8 + 5O_2 \rightarrow 3CO_2 + 4H_2O$ 3

$C_4H_{10} + 13/2O_2 \rightarrow 4CO_2 + 5H_2O$ 4

$C_5H_{12} + 8O_2 \rightarrow 5CO_2 + 6H_2O$ 5

The total amount of CO_2 released according to these equations on basis of percentage as in Table 1 was calculated to be 2.681kW/m^3. The amount of heat radiated from gas flaring is given by equation 6 below (Odigure and Abdulkareem, 2000).

$$Q_{fr} = \frac{q_f \rho_f V_f F_{12} C_{pf}(T_f - T_s)}{A} - \alpha Q_{f_r}(1-a) \quad \text{.......... 6}$$

$$Q_{fr} = \frac{2.681 \rho_f V_f F_{12} C_{pf}(T_f - T_s)}{A} - \alpha Q_{f_r}(1-a)$$

$$Q_{fr} A = 2.681 \rho_f V_f C_{pf} F_{12}(T_f - T_s) - \alpha Q_{f_r} A(1-a)$$

$$Q_{fr} A = 2.681 \rho_f V_f C_{pf} F_{12} T_f - 2.681 \rho_f V_f C_{pf} F_{12} T_s - \alpha Q_{fr} A(1-a)$$

$$T_f - T_s = \frac{A[Q_{fr} + \alpha Q_{fr}(1-a)]}{2.681 \rho_f V_f F_{12} C_{pf}} \quad \text{.......... 7}$$

where T_f temperature of the flared gases, T_s – soil temperature, Q_f heat from the flared gases, Q_{fr} – heat reflected from the flare station, Q_{fa} heat absorbed by the earth from the flared gases, V_f – volume of flared gases, $F_{1\text{-}2}$ the view factor, C_{pf} – specific heat capacity of the flared gases, ρ_f – density of the flared gases, A – area of receiving surface, a – albedo constant (0.31 for tropical soil), α – absorptivity factor; it varies with soil type, and q_f – quantity of heat released by 1m^3 of flared gases (2.681kW/m^3).

Equation 7 is the proposed model equation to be used in determining the soil temperature.

3. Experimental Methodology

The experimental method carried out in this work was aimed at analyzing and determining the effect of heat radiated from gas flaring on the soil in the Niger – Delta area of Nigeria. This method was specifically employed to determine soil temperature at various distances from the flare point. A process industries situated in the Niger – Delta area, performed the experiments mentioned here. The explanation of the experimental method is to enhance understanding of the proposed modeling techniques. These experiments were generally aimed at obtaining the temperature of the soil at about 100cm depth. Temperatures are taken at different distances of 20, 60, 100, 200,500 and 1000meters away from the flare point. The results obtained were recorded and are presented in Table 2.

The model equation was programmed using Q basic programme. The obtained simulated results are presented in Table 3. The obtained simulated results will be used to test the validity of the model equation in respect to the experimental values.

4. Results

The obtained experimental and simulated results are presented in Table 2 and 3.

Table 2: Soil temperature (°C)

Months	Year	Distance (m)						
		20	40	60	100	200	500	1000
October	1997	28.4	28.4	28.5	27.2	28.2	27.8	26.8
November	1997	30.1	29.2	30.6	31.3	30.4	29.1	28.8
December	1997	32.1	30.3	29.3	29.4	29.0	28.9	30.2
January	1998	30.8	30.7	30.3	30.7	30.3	28.3	28.3
February	1998	34.3	32.2	32.1	31.8	31.3	31.1	31.5
March	1998	35.1	33.9	33.1	33.2	30.7	30.1	30.8
April	1998	37.0	35.6	34.6	35.1	34.4	34.4	34.5
May	1998	32.9	32.8	33.2	33.0	33.7	33.7	33.4
June	1998	28.0	26.8	26.3	25.5	26.3	26.3	26.0
July	1998	29.2	29.0	28.3	28.3	28.8	28.8	29.1
August	1998	29.0	30.0	29.0	29.0	28.0	28.5	28.0
September	1998	32.0	28.5	28.2	27.4	28.7	27.5	27.0

Table 3. Computed Soil temperature (°C) at various volume of flare gas and heat radiation

Radius (m)	Volume of flared gas (m^3/day).							
	Heat Radiation = 0.0388 kW/m^2				Heat Radiation = 0.041kW/m^2			
	300	500	600	1000	300	500	600	1000
20	38.99	39.0	39.0	39.0	38.99	39.0	39.0	40.00
60	38.98	38.98	38.98	38.99	38.98	38.98	38.99	39.99
100	38.96	38.96	38.96	38.97	38.96	38.97	38.98	39.99
200	38.86	38.9	38.93	38.95	38.85	38.8	38.93	39.96
400	38.5	38.6	38.7	38.8	38.4	38.5	38.7	39.82
600	24.8	31.7	31.9	32.1	31.2	31.6	31.8	33.12
800	23.9	31.2	31.4	31.8	30.2	30.9	31.4	32.83
1000	22.7	30.5	30.8	31.5	29.0	30.0	30.7	32.45
1200	21.7	24.1	30.1	31.0	27.5	28.9	29.9	31.99
1500	18.7	21.6	22.4	23.8	18.3	20.6	22.1	24.69
1800	15.5	19.7	20.7	22.8	14.9	18.2	20.5	23.68
2000	13.5	18.2	19.5	22.1	13.8	16.4	19.1	22.90

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

Man expanding industrial and urban activities has reached a level at which their effects have become global in nature (Boloion, 1991). Such activities as we have during gas flaring and combustion of other gases, not only alters the ecosystem but affects the structures, vegetation, human health and migration. Gas flaring in the Niger- Delta area pollutes the entire ecosystem thereby making the environment unbearable for human lives. The surrounding soil mantle is continuously being heated thereby raising the level of temperature of that soil to a much higher value, hence making survival of plants and vegetation difficult via absorption of the heat from the flare source. Most plants and shrubs/vegetable that are mainly grown in this area, can tolerate temperature ranges from 16°C – 28°C, anything higher affects their growth rate hence resulting in dislocation of green leaves and consequently poor yield.

On the basis of available experimental data of soil temperature obtained at various distance up to 1000m from flare station as shown in Table 2 and that of simulated values at various distances up to 2000m is shown in Table 3, it could be observed that at any average distance of about 50m, the heat felt was as high as 40°C in the soil (Alakpodia, 1980). It could be observed that the most affected soil area are consequently unsuitable for plant and human survival, 600m away from the flare station can be said to be un safe zone especially for farming of vegetables and tubers that can survive soil temperature between 25°C – 30°C (Brady, 1990). However, effects of this heat from gas flaring point, felt over these distances depend on the volume of gas that was flared and also the absorptivity of the soil in the area (Table 3).

It could be observed from the simulation results shown in Table 3 that an increase in volume of gas flared will cause an increase in soil temperature at any particular distance. Here, one could also see that soil temperature reduces as distance increases and this could possibly be attributed to the percentage of heat absorbed by the soil at various distances.

However, there are some variations between the experimental and simulated results and this could be due to reasons like, the assumption made during the conceptual stage of the mathematical equation, the non patterned nature of experimental data which may be due to the fact that the weather was not considered, also the variation may be due to atmospheric conditions such as wind speed, humidity and temperature felt at various distance. However, the soil temperatures obtained showed that the model equation could be employed in simulating the effect of heat on the soil temperature in that area since it showed some remarkable conformity with experimental values.

5. Conclusion

From the research work, it could be deduced that the model equation generated reasonably reflect the considered variable. Hence the simulation results conform to the experimental values. Therefore, it can be deduced that the soil temperature at various distance depends on the volume of gas flared and absorptivity of the soil. The paper recommends that a safe distance of at least 600m from the flared station should be observed to ensure safety of lives and vegetations.

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