Deterministic Model for Noise Dispersion from Gas Flaring: A Case Study of Niger – Delta Area of Nigeria

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Original scientific paper
Received: July 7, 2005
Accepted: February 1, 2006

Noise is an audible acoustic energy that adversely affects the health, physiological and psychological well being of the individuals or populations. One of the major pollutants from gas flaring is the noise emanating from gas flaring stations in the Niger – Delta area of Nigeria. Noise dispersion produces many adverse effects on man and animals. Experimental analysis of noise dispersion and weather conditions used for simulation has been carried out, the modeling and simulation of noise dispersion from flare stations using visual basic programme is the main focus of this work. Results obtained shows some variation between the simulated results and experimental results, with correlation coefficient ranging from 0.955 – 0.995. Simulation results of the developed model show that the noise intensity level reduces with increasing in distance from the flare point and that weather conditions has an important influence on noise dispersion.

Key words:
Gas flaring, noise dispersion, pollution, modeling and simulation

Introduction

Nigeria is a country so blessed with natural gas that makes it ranks 9th in the world and 2nd in Africa in its reserves.[1] Nigeria has an estimated 145 million cubic meter of proven gas, but due to unsustainable exploration in Nigeria, the country flares 75 % of the gas it produces and re – injects only 12 % to enhance oil recovery.[1] It is estimated that about 1.6 million cubic meter of gas is currently being flared in Nigeria, the highest in any member nation of OPEC.[3] This is an enormous flare amount which accounts for about 19 % of the total gas flare globally. This flaring takes place in the Niger – Delta area of Nigeria and is a major cause of environmental pollution in the region and also the major source of threat to human health. A World Bank study defining an environmental development strategy for the Niger – Delta, estimates that as much as 75 % of all natural gas from petroleum production in Nigeria is flared compared to 0.6 % in USA and 4.3 % in the UK.[1] The flared of gas is a very serious hazard, the multitude of flares in Niger –Delta resulted in burning of gas at temperature ranging from 1300 °C to1400 °C and heat up the environment.[4] Taken into consideration the serious deterioration of the basis characteristic of the environment as result of harmful pollutants released into the atmosphere. The practice of gas flaring is not only wasteful in terms of resources but also extremely harmful to the human health and environment. Human health has suffered so much that Niger –Delta is now a place, where life is short and unpredictable where so much wealth is extracted and, where so much wretchedness is evident.[5] The extent of human damage attributed to gas flaring is unclear, but reports show that there are an unusual high incidence of astounding bronchitis, skin and breathing problems in oil producing communities.[1] The reactive effect of gas flaring does not stop on human health and environment alone, but it also affects the growth of plants. Research by ecologist suggested that routine flaring of gas at Niger-Delta has resulted in stunted plant growth and reduced crop yield in the region.[6] Some of the flaring stations are only a few meters from human dwellings. Consequently, the inhabitants of the area are exposed to perpetual heat, high noise level, and constant daylight conditions with physiological and psychological disorder that goes with them. This work has the aim to develop a deterministic model for noise dispersion from gas flaring station in the Niger – Delta area. This paper is divided into 7 sections i.e. introduction to the work, noise pollution and effects, mathematical modeling, experimental analysis, computer programme results, comparison and discussion of results, and conclusion.

Noise pollution and effects

Noise is a legitimate environmental pollutant, but much less research, funding and attention are placed on it when compared to other pollutants. The

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main reasons are the difficulties with defining and measuring sources and enforcing the regulation. This fact coupled with society's ignorance of noise and its health effect hinder attempts to prevent and properly manage the problem. The emphasis of this research is centered upon the noise intensity emanating from gas flaring stations in the Niger–Delta. Various types of machinery are involved in gas flaring and they represent artificial noise, because they are of predominantly low or high frequencies as well as tonal components. The noise from this source is impulsive and also presents unpleasant and temporal sound patterns.[7,8] The continuous exposure to loud noise, through its effect on the nervous system, can produce harmful effect on many systems of body, primarily cardiovascular system.[9] Some studies have indicated blood pressure to be irregular in noise-exposed workers, and in populations living in noisy areas near industrial zones and airports, than in control populations.[10]

Noise pollution is the excessive noise or unwanted sound contributed to the environment by human activities. Noise is considered a pollutant when it is present in sufficient quantity and intensity to cause psychological damage to people in the environment.[11] Like other pollutants, noise is often concentrated where population and activities are concentrated. The problem of noise pollution is acute on street where heavy traffic is a major source of noise, building, and construction sites. In industrial cities, factories can be further sources of noise. Mechanized industry created serious noise problems, subjecting a significant fraction of the working population to partially harmful sound pressure levels (sound intensity). In industrialized countries it has been estimated that 15-20 % or more of the working population is affected by sound pressure levels of 75 dB – 85 dB.[12] Noise is a stress, and as such produces many varied effects on man and other animals. In heavy industries neuro-sensory hearing loss among employees occurs frequently and is irreversible. In addition, many studies have indicated that continued exposure to loud noise has effect on the nervous system. Some investigators have also pointed to a casual role of noise in such diverse ailments as ulcers and hives.[13] Loud noise also influences man's physiological well being and investigations on both animal and human subjects have revealed that noise can affect foetuses, causing them to stirr in the uterus and perhaps be overactive, and be a subject to gastrointestinal upset after birth.[10] It is widely believed that people become accustomed to noise and that therefore it dose not harm them. However, unlike the eyes, which can be closed against strong light, the ears are always open and vulnerable. Loud noises cause effects that the recipient cannot control and to which his/her body never gets accustomed. The blood vessels constrict, the skin pales, the muscles tense, and one of the adrenal hormones is suddenly released into the blood stream increasing the physical signs of tension and nervousness.[9] Other investigators have shown that even mild sensory and mental annoyance resulting from noise pollution can provoke significant elevations in cortical (an adrenal hormone) levels in plasma.[14] This in turn increases the heart rate of blood pressure, especially in emotionally excitable persons.

Mathematical modeling and simulation

The exploitation and exploration of crude petroleum and natural gas in the Niger – Delta area, region of Nigeria, has resulted in wasting of resources through flaring. The multitude of flaring activities in the region has enormous adverse effects on both the environment and its inhabitants; these include the emission of greenhouse gases, smoke, soot, and noise. The noise emanates from gas flaring constituting a local problems in the immediate surrounding of the flare stations.

Assumptions

The following assumptions were made in developing the mathematical model for noise dispersion from gas flaring [(Odigure et – al, 2004)]:

1. Sound source is considered as a line source i.e. sound radiated in a cylindrical manner.
2. The intensity at a point is equal to the sum of direct intensity and reverberation intensity.
3. Reverberant field on diffusion has a sound energy density that is constant.
4. At steady state condition, power input to the reverberant field is equal to the rate of energy extracted from it.
5. Inverse square law is obeyed.
6. The initial wind blowing with a velocity w in the direction of sound propagation and the direction of wind velocity perpendicular to the discharge.
7. The effect of gravitational force will be neglected. So that constant equilibrium density of the air and constant equilibrium pressure in the air has uniform value through out.
8. The air is homogenous, isotropic and perfectly elastic.

Odigure et al., 2003[15] shows that noise intensity level is:

$$L_p = 10\log\left(\frac{16P(1-\alpha)+\tau P\alpha}{I_{\mathrm{ref}}\pi l^2\alpha}\right) \tag{1}$$

where: P is the power of machine (kW), is the directivity factor, depending on the situation of the source, α is the absorption coefficient of the surface and I_{ref} (kW m^{-2}) is the reference noise intensity.

From assumption 5, inverse square law is obeyed i.e for uniformly diverging wave (with no local reflecting surface or sources), the loss in noise intensity is inversely proportional to the logarithm of square of the distance from the source.[14] Therefore,

$$L_i = 10\log\left(\frac{16P(1-\alpha)+\tau P\alpha}{I_{ref}\pi l^2\alpha}\right) - \log\left(\frac{l_{tot}}{l}\right)^2 \quad (2)$$

where l_{tot} total distance (m), l = distance step length (m)

$$\alpha = \left(\frac{\gamma-1}{\gamma}\right)\frac{\dot{T}}{2u} \quad (3)$$

where: γ = ratio of specific heat, u = speed of sound in air (m s^{-1}), $\dot{T}$ = rate of cooling at constant volume of gas (K s^{-1})

$$\text{but } u = \sqrt{\frac{\gamma\, p_r}{\rho}} \quad (4)$$

and

$$p_r = \frac{nRT}{V} \quad (5)$$

where: R is the universal gas constant (kJ kmol^{-1} K^{-1}) , T is the temperature (K), V is the volume of gas (m^3), ρ is the density of air (kg m^{-3}) and p_r is the pressure (N m^{-2}), and n is the amount of substance (kmol)

Substitute equation (5) into (4) and rearrange to make γ the subject gives:

$$\gamma = \frac{u^2 V\rho}{nRT} \quad (6)$$

Substitute equation (6) into (3) to obtain:

$$\alpha = \frac{\dot{T}}{2u}\left(1 - \frac{nRT}{u^2 V\rho}\right) \quad (7)$$

Relationship between density and humidity[16]

$$s = 0.622\varphi\left(\frac{\rho_{ws}}{\rho - \rho_{ws}}\right) \quad (8)$$

where: s_{sp} is the specific humidity of air vapour mixture (kg kg^{-1}), φ_r is the relative humidity (%), ρ_{ws} is the density of water vapour (kg m^{-3}) and ρ is the density of air (kg m^{-3}).

From equation (8)

$$\rho = \rho_{ws}\left(\frac{0.622\varphi}{s} + 1\right) \quad (9)$$

Substitute equation (9) into (7) to obtain:

$$\alpha = \frac{\dot{T}}{2u}\left(1 - \frac{nRTs}{u^2 v\rho_{ws}(0.622\rho + s)}\right) \quad (10)$$

Substitute equation (10) into (2) to obtain:

$$L_p = 10\log\left(\frac{16p - \frac{p\dot{T}}{2u}\left(1-\frac{nRTs}{u^2 v\rho_{ws}(0.622\rho+s)}\right)(16-\tau)}{I_{ref}\pi l^2 \frac{\dot{T}}{2u\left(1-\frac{nRTs}{u^2 v\rho_{ws}(0.622\rho+s)}\right)}}\right) \cdot$$

$$\cdot \log\left(\frac{l_{tot}}{l}\right)^2 \quad (11)$$

If the wind blows with a velocity w (m s^{-1}) in the direction of sound (from assumption 6), then the resultant velocity of sound will be (u + w), then equation (11) becomes:

$$L_p = 10\log\left(\frac{16p - \frac{p\dot{T}}{2(u+w)}\left(1-\frac{nRTs}{(u+w)^2 v\rho_{ws}(0.622\rho+s)}\right)(16-\tau)}{I_{ref}\pi l^2 \frac{\dot{T}}{2(u+w)\left(1-\frac{nRTs}{(u+w)^2 v\rho_{ws}(0.622\rho+s)}\right)}}\right) \cdot$$

$$\cdot \log\left(\frac{l_{tot}}{l}\right)^2 \quad (12)$$

Equation 12 is the deterministic model equation for noise dispersion from gas flaring and the simulation is obtained by computer simulation programming using visual – basic.

Experimental Analysis

Methodology

Sound level meter was used to measure the intensity of noise from the flare station. The meter was placed at required distance of 20, 40, 60 and 80 m away from the flare point. The microphone of the equipment was adjusted to ensure that the incoming sound waves actuate temporary compression and refraction of air particles and then sets the diaphragm of the microphone on vibration. The vibrations are in turn converted to a sound level i.e. noise intensity reading on the meter, expressed in unit of measure called decibel (dB). The weather conditions in the flare stations i.e. wind speed, humidity, temperature, and volume of gas flared were also measured. Four flare stations are studied.

Computer programme and results

Simulation of the model is the use of computer code to show the operation behaviour of the system. The model equation was simulated using visual basic programme with volume of gas flared, wind speed, temperature, relative humidity, specific humidity, density of water vapour, distance and distance step length as the input and the output is the noise intensity level. Data used as input for simulation for different stations are presented in Tabl 1 to 4, experimental results are presented in Fig. 1 to 3, Fig. 4 to 7 show the simulated results while Fig. 8 represents comparison of experimental with simulated results.

Table 1 – *Experimental data used for the simulation of noise intensity level for station 1*

Month	Volume of flow rate gas flared Q / m^3 s^{-1}	Wind speed w / m s^{-1}	Surrounding temperature T /°C	Relative humidity φ / %	Specific humidity s / kg kg^{-1}	Density of water vapour ρ_{ws} / kg m^{-3}
January	9.3053	2.80	36	80	1.67	0.0421
February	0.7584	2.20	36.5	63	1.35	0.0403
March	8.3466	2.90	36.2	80	1.69	0.0425
April	12.5803	1.39	35.0	85	1.69	0.0401
May	16.0909	2.20	33	86	1.93	0.0362
June	10.3049	1.81	30	90	1.33	0.0304
July	9.6075	1.80	34.6	90	1.74	0.0393
August	7.2855	1.39	33.5	91	1.67	0.0372
September	9.0678	2.88	33.2	89	1.59	0.0366
October	7.0740	2.78	34	87	1.64	0.0382
November	11.1565	1.38	32	88	1.48	0.0343
December	8.7081	1.28	35	82	1.63	0.0401

Table 2 – *Experimental data used for the simulation of noise intensity level for station 2*

Month	Volume of flow rate gas flared Q / m^3 s^{-1}	Wind speed w / m s^{-1}	Surrounding temperature T / °C	Relative humidity φ / %	Specific humidity s / kg kg^{-1}	Density of water vapour ρ_{ws} / kg m^{-3}
January	0.4618	2.88	37.5	79	1.78	0.0452
February	0.4784	2.80	37.5	84	1.89	0.0452
March	0.4763	2.22	37.5	83	1.87	0.0452
April	0.0178	1.39	38	84	1.94	0.0464
May	0.0136	3.40	38	86	1.99	0.0464
June	0.0155	1.04	39.8	88	2.20	0.050
July	0.0078	1.41	34.2	89	1.72	0.039
August	0.0043	3.33	30	88	1.30	0.030
September	0.0052	2.22	30.4	91	1.39	0.031
October	0.0146	2.78	31	90	1.42	0.0032
November	0.0836	1.38	33	87	1.35	0.036
December	0.0836	1.38	33	75	1.34	0.036

T a b l e 3 – *Experimental data used for the simulation of noise intensity level for station 3*

Month	Volume of flow rate gas flared Q / m^3 s^{-1}	Wind speed w / m s^{-1}	Surrounding temperature T / °C	Relative humidity φ / %	Specific humidity s / kg kg^{-1}	Density of water vapour ρ_{ws} / kg m^{-3}
January	0.3421	2.80	31.8	72	1.21	0.034
February	0.3243	2.20	37.0	76	1.67	0.044
March	0.3847	2.80	36.8	75	1.63	0.0436
April	0.0945	1.39	36.9	83	1.81	0.0438
May	0.0803	2.20	34.0	84	1.60	0.0382
June	0.0039	1.81	31.2	86	1.40	0.033
July	0.2318	1.50	33.0	90	1.60	0.036
August	0.2704	1.39	32.8	88	1.57	0.036
September	0.0276	2.78	31.0	91	1.44	0.032
October	0.1179	2.78	32.0	87	1.46	0.034
November	0.1530	1.38	34.0	86	1.62	0.038
December	0.2182	1.28	33.5	82	1.50	0.037

T a b l e 4 – *Experimental data used for the simulation of noise intensity level for station 4:*

Month	Volume of flow rate gas flared Q / m^3 s^{-1}	Wind speed w / m s^{-1}	Surrounding temperature T / °C	Relative humidity φ / %	Specific humidity s / kg kg^{-1}	Density of water vapour ρ_{ws} / kg m^{-3}
January	0.0645	2.20	37.5	67	1.51	0.0452
February	0.2356	2.75	35.5	74	1.51	0.0411
March	0.0552	1.39	36.5	83	1.78	0.043
April	0.1779	1.28	33.5	84	1.54	0.0370
May	0.1984	1.75	32.0	85	1.44	0.0343
June	0.2645	2.0	33.6	88	1.63	0.0343
July	0.0318	1.94	31.0	90	1.33	0.0320
August	0.0027	1.38	30.0	90	1.33	0.030
September	0.0345	2.0	32.1	89	1.54	0.035
October	0.0874	1.38	33.0	89	1.59	0.036
November	0.2645	1.34	36.0	84	1.75	0.042
December	0.3161	2.60	34.1	77	1.45	0.038

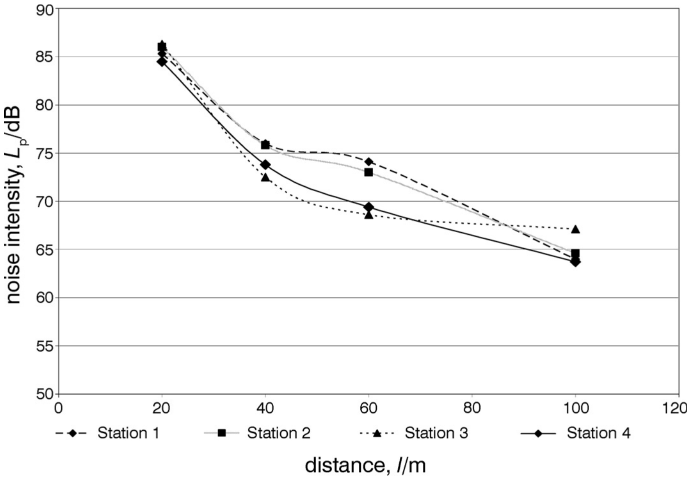


Fig. 1 – *Experimental results for the month of November (Abdulkareem, A. S., Odigure, J. O., Deterministic model for noise dispersion from gas flaring: A case study of Niger – Delta area)*

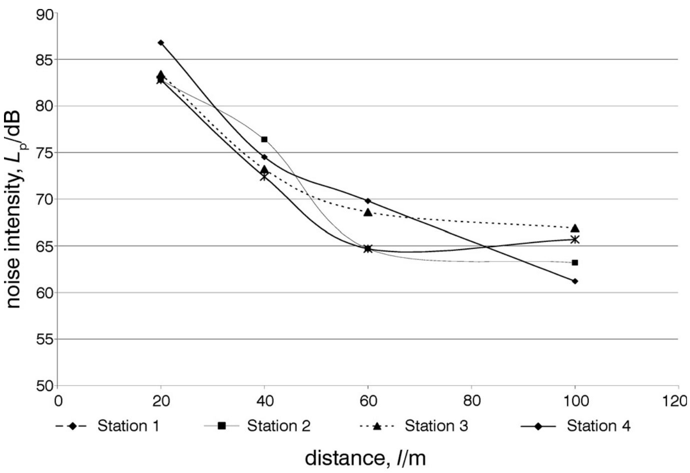


Fig. 2 – *Experimental results for the month of December (Abdulkareem, A. S., Odigure, J. O., Deterministic model for noise dispersion from gas flaring: A case study of Niger – Delta area)*

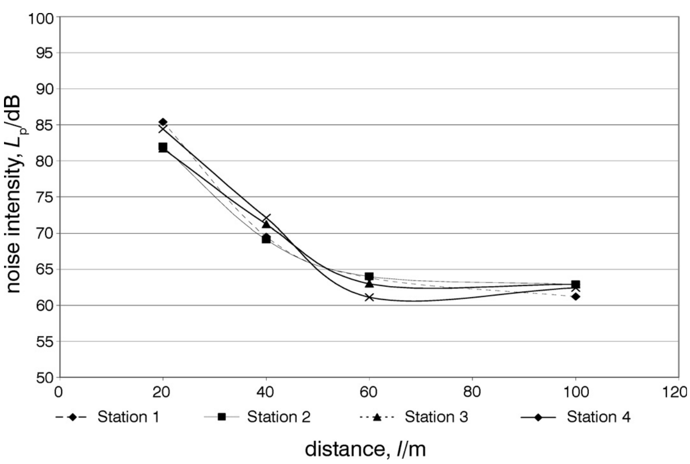


Fig. 3 – *Experimental results for the month of January (Abdulkareem, A. S., Odigure, J. O., Deterministic model for noise dispersion from gas flaring: A case study of Niger – Delta area)*

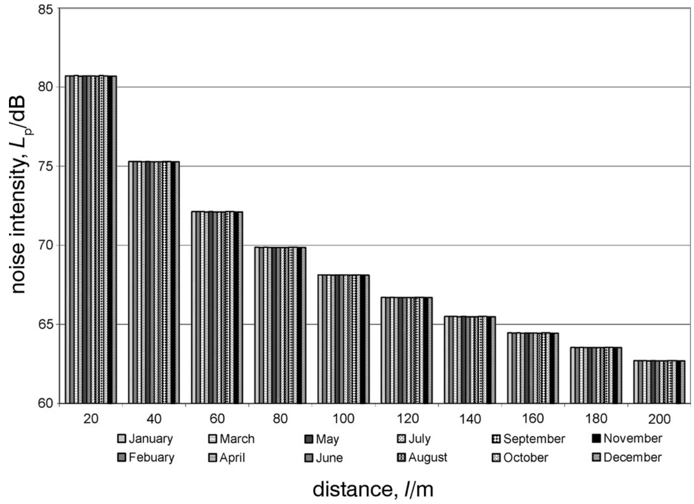


Fig. 4 – *Computed noise intensity level for station 1 (Abdulkareem, A. S., Odigure, J. O., Deterministic model for noise dispersion from gas flaring: A case study of Niger – Delta area)*

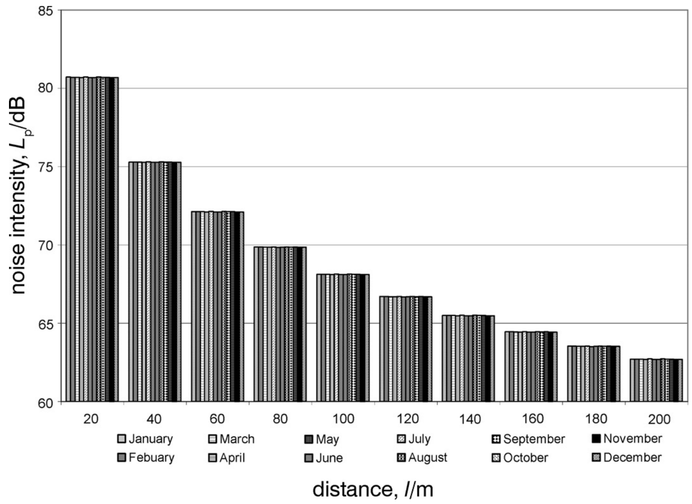
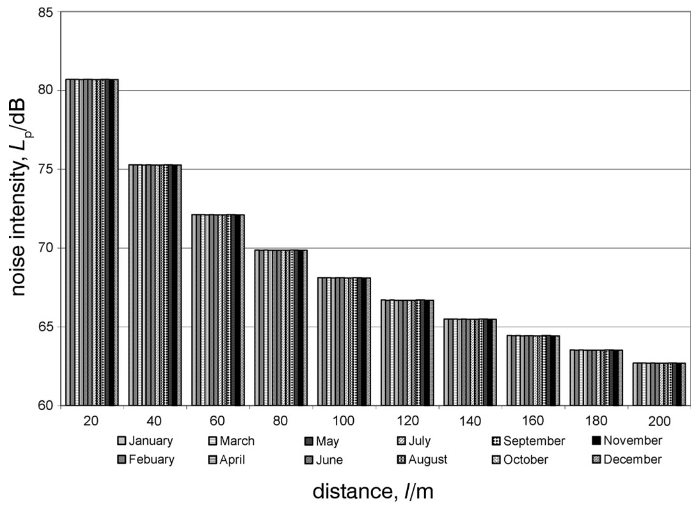
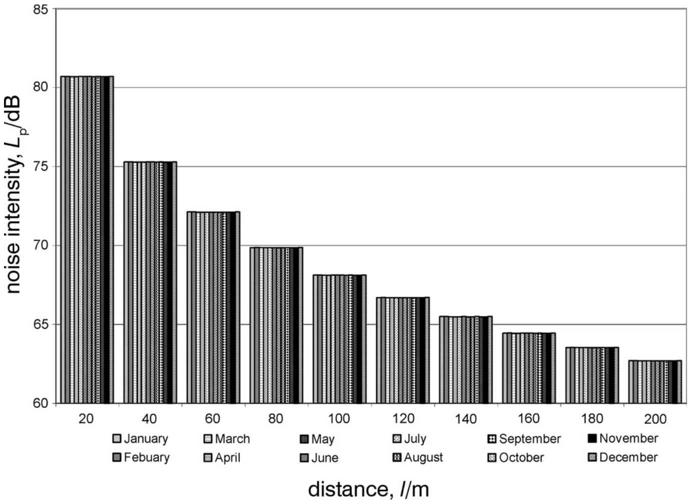


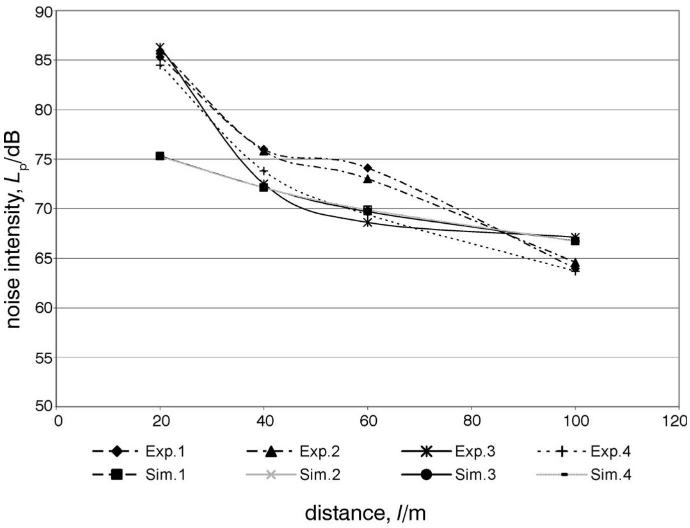
Fig. 5 – *Computed noise intensity level for station 2 (Abdulkareem, A. S., Odigure, J. O., Deterministic model for noise dispersion from gas flaring: A case study of Niger – Delta area)*



Fig, 6 – *Computed noise intensity level for station 3 (Abdulkareem, A. S., Odigure, J. O., Deterministic model for noise dispersion from gas flaring: A case study of Niger – Delta area)*



F i g , 7 – *Computed noise intensity level for station 4 (Abdulkareem, A. S., Odigure, J. O., Deterministic model for noise dispersion from gas flaring :A case study of Niger – Delta area)*



F i g , 8 – *Comparison of experimental with simulated results for the month of January (Abdulkareem, A. S., Odigure, J. O., Deterministic model for noise dispersion from gas flaring: A case study of Niger – Delta area)*

Comparison and discussion of results

From the experimental results shown in figures 1 to 3, at various distances from the flare stations, it could be observed that the noise intensity level varies for the four stations and month. The results revealed that the noise intensity varies with distance from the flare point. Also affecting the noise intensity is the weather condition i.e. temperature, humidity, density of water vapour and volume of gas flared. It could also be noticed from the results that the people in the area are exposed to possible danger from the noise pollution. Results also revealed that the most dangerous zone from the flare station is within 20 – 80m radius range from flare station. Noise intensity within this range distance exceeds the World Health Organization Standard (WHO) set limit. However, this effect might exceed the 80 m distances depending on the volume of gas flared and weather condition. The limit was set in view of the adverse psychological and physiological effect loud noise cause on humans and environment. World Health Organization guideline stated that exposure to noise intensity exceeding 70 dB over 24 h could lead to heavy impairment among other physiological effect.[14]

The simulated results are presented in tables 8 –12, while the quantities used in simulating the model are presented in tables 1 to 3. Results obtained from the simulation shows that noise intensity varies with the distance from the flare station, volume of gas flared, wind speed, ambient temperature, relative humidity etc. The variations may be attributed to unbalanced process equipment and different weather conditions. At low volume of flare, the process equipment is unbalanced, which results in vibration of the machine and consequently noise is generated. Also affecting the value of noise radiation is the weather condition of the flare station, some of which include the wind speed, ambient temperature, relative humidity etc. The weather has a fundamental influence on sound propagation out doors. Errors of the order of 20 dB could be introduced if weather is not taken into account.[10] Relative humidity is also an important factor in sound propagation, the more humid the air is, the lower sound waves travel in it.[16] In summer, ambient temperature decreases with height causing sound waves to be refracted away from the earth, in winter with temperature inversion, temperature increased with height and refraction takes place towards the earth, causing the noise intensity to be increased rather than attenuated. The Niger – Delta area of Nigeria experiences both temperate and rainforest weather phenomena. Comparison of experimental results with simulated results shows some variation as shown in figure 8, with correlation coefficient ranging from 0.955 to 0.995. This analysis was carried out using Microsoft Excel. The variations between experimental and simulation results can be attributed to the some assumptions made at initial stage of modeling such as wind speed, temperature, pressure, and weather condition. The assumption may not conform to prevailing atmospheric condition. The simulated results are an instantaneous results, they measure possible amount of noise intensity that could be dispersed during flaring at a given time, while the experimental results are a measure of noise intensity for the prevailing meteorological conditions.

Conclusion

From this research, it could be deduced through the experimental and simulation results, that the noise intensity reduces with increasing distance from the flare station. It can also be deduced that the volume of gas flared and the different weather conditions greatly affect the noise dispersion pattern. Noise dispersion from the flare station is adversely felt within 20 – 80 m away from the flare station.

List of symbols

I_{ref} – reference noise intensity, kW m^{-2}
L_p – noise power level, dB
l – distance step lenght, m
l_{tot} – total distance, m
n – amount of substance, kmol
P – power, kW
p_r – pressure, Nm^{-2}
Q – volume flow rate, m^3 s^{-1}
R – universal gas constant, kJ kmol^{-1} K^{-1}
s – specific humidity, kg kg^{-1}
T – temperature, K
$\dot{T}$ – rate of cooling at constant volume, K s^{-1}
t – time, s
u – speed of sound in air, m s^{-1}
V – volume, m^3
w – wind speed, m s^{-1}

Greek letters

α – absorption coefficient, K m^{-1}
γ – ratio of heat capacities, 1
ρ – density, kg m^{-3}
φ – relative humidity, %
τ – directivity factor, 1

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