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Mathematical Modeling and Computer Simulation of Noise Radiation by Generator

J.O. Odigure, A.S AbdulKareem and O.D Adeniyi

Chemical Engineering Department, Federal University of Technology
Minna, Niger State, Nigeria

Abstract

The objects that constitute our living environment have one thing in common – they vibrate. In some cases such as the ground, vibration is of low frequency, seldom exceeding 100 Hz. On the other hand, machinery can vibrate in excess of 20 KHz. These vibrations give rise to sound – audible or inaudible – depending on the frequency, and the sound becomes noise at a level. Noise radiations from the generator are associated with exploitation and exploration of oil in the Niger-Delta area that resulted public annoyance, and it is one of the major causes of unrest in the area. Analyses of experimental results of noise radiation dispersion from generators in five flow stations and two gas plants were carried out using Q-basic program. It was observed that experimental and simulated model values conform to a large extent to the conceptualized pollutant migration pattern. Simulation results of the developed model showed that the higher the power rating of the generator, the more the intensity of noise generated or produced. Also, the farther away from the generator, the less the effects of radiated noise. Residential areas should therefore be located outside the determined unsafe zone of generation operation.

Keywords: *Mathematical modeling, computer simulation, noise radiation, generator, environment, vibration, audible, frequency.*

1. Introduction

Environmental pollution is the direct or indirect alteration of physical, thermal, biological, or radioactive properties of any part of the environment in such a way as to create a hazard or potential hazard to health (Allaby 1990). Environmental pollution may occur naturally, but the term is commonly applied to changes brought by the emission of industrial pollutants, or by the careless discharge, or disposal of human domestic wastes or sewage. The term includes the production of excessive noise (e.g. by aircraft, road vehicles or factories) and the release of excessive heat (Gavriel 1996; Perry and Green 1997). Industrialization is seen to be playing a leading role in environmental pollution. Industrial wastewater, effluents, intolerable and continuous exposure of human beings to high levels of noise appear to be part of the ills of industrialization. Domestic and industrial use of generators has not in any way helped in the attempt to control noise pollution especially in developing countries. Noise is the most widespread industrial hazard in Britain today and deafness is its common consequence (Leventhall 1998). Some occupational-health studies indicate that noise above 85 decibels (dB) can harm a fetus (Berglund and Lindvall 1995).

Noise is a problem that affects everybody. It is likely to continue as a major issue well into the next century (Odigure 1999). In industrialization countries, it has been estimated that 15-20% or more of the working population is affected by sound pressure levels of 75-85 dB (Jackson *et al.*, 1989). This noise is due to machinery of all kinds and increases with the power of the machines (Leventhall 1998). Noise as a source of environmental pollution and its long-term effect on the auditory system of humans has become a global concern. Much legislation has been made regarding the regulation of sound radiation from machineries (e.g. industrial machine, cars, aircrafts, generator). A close observation of the Nigerian environmental protection strategies shows that less attention is being paid to noise as a source of environmental pollution (Odigure and AbdulKreem 2002). This may be due to the inability of the government and people to quantify the resultant effect of noise from process industries on the immediate environment, which could have varying degrees effects ranging from disturbance on work, to rest, sleep, and communication (Gavriel 1996). It is on this basis that a mathematical model, which is a tool of control, should be developed for noise radiation from generators in the oil field located in the Niger-Delta area of Nigeria. This model would in turn be used in predicting the effects of noise on the immediate environment.

This objective can be achieved via the realization of the following aims:

1. Simulating the developed computer program to find the interaction between the various parameters affecting noise dispersion, i.e. distances, temperature, wind speed, and power of the generator.
2. Determine a safe distance for farming and habitation.

2. Experimental Methodology

The sound pressure level meter was used to measure the intensity of noise from generators in the flare stations. The mode of operation of the meter, roughly imitates the functioning of the ear. The microphone of the equipment was adjusted to ensure that the incoming sound wave are accurate, and the temporary compression and rarefaction of particles of air set diaphragm of the microphone on vibration that caused a fluctuation in the pressure of the air adjacent to the diaphragm. The fluctuation in the air pressure adjacent to the diaphragm causes a vibration of the diaphragm, which is converted to variation in an electric current in the meter. The variation was in turn converted to a sound pressure level, i.e. noise intensity reading on the meter, expressed in units of measure, called decibel (dB). The measurements were carried out for various distances of 20, 40, 60, 100, 200, 500, and 1000 m from the generator house and the results were recorded. Companies in the Niger-Delta area performed these experiments. The explanation of the experimental method is to enhance understanding of the proposed modeling and verify its validity.

3. Conceptualization of Modeling Technique

A generator may be described as any means by which mechanical power is transmitted into electrical power (Sybil 1983). While in operation, generators themselves vibrate and they cause their immediate surrounding to vibrate. The resultant effect of vibration is noise generation. The level of noise produced by a generator depends largely on the power out put. Generator operation is on 24-hour basis in the oil field and resulted in a continuous generation of the noise into the vicinity.

3.1 Assumptions

The following assumptions were made in developing mathematical equations for noise radiation from the generator.

(i) Sound source is considered as a line source, i.e. sound is radiated in a cylindrical manner.

(ii) Reverberant field is diffuse and has a sound energy density E, i.e. E is constant.

(iii) Steady state condition is associated, i.e. power input to the reverberant field is equal to the rate of energy extracted from it.

(iv) Inverse square law is obeyed.

(v) The wind blowing with a velocity V in the direction of sound propagation and the direction of wind is perpendicular to the discharge.

(vi) The effect of gravitational pull will be neglected so that constant equilibrium density of the air and constant equilibrium pressure in the air has uniform value throughout.

(vii) The air is homogenous, isotopic and perfectly elastic.

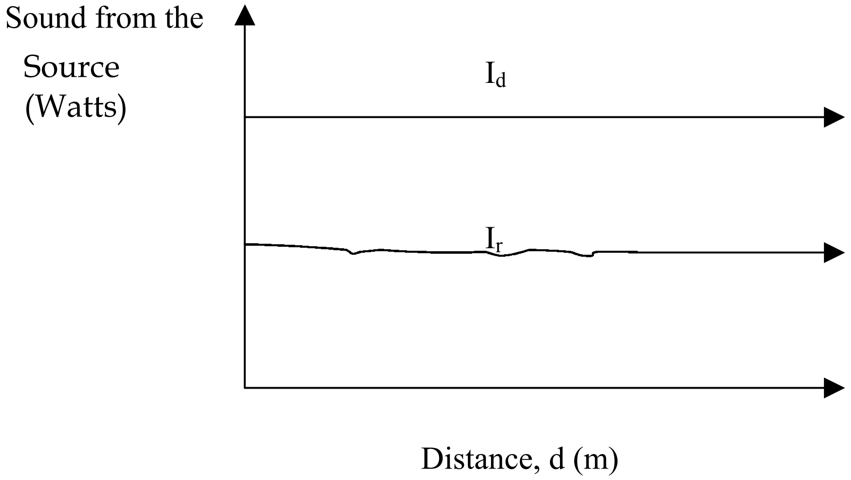

Fig.1. The schematic representation of noise intensity

3.2 Reverberant Field

Consider sound power *w* watts from the source. The sound power remaining after one reflection is:

$$w - \alpha w \quad \text{.......................... (1)}$$

$$w(1-\alpha) \quad \text{...................... (2)}$$

$$E = \frac{P_r^2}{\rho\ C^2} \quad \text{........ (5)}$$

$$w(1-\alpha) = \frac{EC\alpha\ S}{4} \quad \text{...... (4)}$$

Equation (1) is the sound power input to the reverberant field.

α = Absorption coefficient of the surface.

Total energy in space = nEV

Where
E= sound energy
n= number of reflection
V = volume.

But Lawrence *et al.* (1985) stated that:

$$\textit{Energy absorbed} \text{ per reflection is } \frac{EC\alpha\ S}{4} \quad \text{............ (3)}$$

Where C= acoustic velocity (m/s)
S = surface area (m^2)

Under steady state condition, power input to the reverberant field equal to the rate of energy extracted from it.

But,
Where Pr = root mean square sound pressure in reverberant field.

ρ= Density (kg/m^3)

Which implies

$$w(1-\alpha) = \frac{P_r^2\alpha\ CS}{4\rho\ C^2} = \frac{P_r^2\alpha\ S}{4\rho\ C} \quad \text{........ (6)}$$

But,

$$\frac{p_r^2}{\rho\ c} = I_r = \text{ Intensity in reverbrant field.}$$

Therefore,

$$w(1-\alpha) = \frac{\mathrm{I_r}\alpha\ \mathrm{s}}{4} \text{..............} (7)$$

$$\mathrm{I_r} = \frac{4w(1-\alpha)}{s\alpha} \text{..................} (8)$$

3.3 Direct Field

Consider a noise source of W watts situated in a place at a point d meter away:
The intensity I_d is

$$I_d = \frac{QW}{\pi\ \mathrm{d}^2} \text{.................} (9)$$

Where
Q = directory factor depending on the situation of the source.

Total intensity I_T

$$I_T = I_r + I_d$$

$$I_T = \frac{4w(1-\alpha)}{\mathrm{s}\alpha} + \frac{Qw}{\pi\ \mathrm{d}^2} \text{..........} (10)$$

But $\mathrm{s} = \pi\ \mathrm{d}^2 = \mathit{Area}$ of sphere.

Then

$$I_T = \frac{4w(1-\alpha)}{\pi\ \mathrm{d}^2} + \frac{Qw}{\pi\ \mathrm{d}^2} \text{..........} (11)$$

Noise intensity level is given by Dix, 1981 as:

$$\mathrm{L_I} = 10\log\frac{I_T}{I_{ref}} \text{...................} (12)$$

I_{ref} = Reference intensity = 10^{-9} Kw/m^2.
Substitute quation (11) into (12) to obtain

$$L_I = 10\log\left(\frac{4w(1-\alpha)+Qw\alpha}{I_{ref}\pi\ \mathrm{d}^2\alpha}\right) \text{..........} (13)$$

$$L_I = 10\log\left(\frac{4w(1-\alpha)+Qw\alpha}{I_{ref}\pi\ \mathrm{d}^2\alpha}\right) - \log\left(\frac{d_T}{d}\right)^2 \text{.......} (14)$$

From assumption (v) i.e inverse square law:

$$\alpha = \left(\frac{\mathrm{r}-1}{r}\right)\frac{q}{2u} \text{.............} (15)$$

Where

$\mathrm{d_T}$ = total distance

But
R= ratio of specific heat

$$u = \sqrt{\frac{rp}{\rho}} \text{..............} (16)$$

$$\text{Pressure , } \mathrm{p} = \frac{\mathrm{RT}}{\mathrm{V}}$$

$$\mathit{Then}\ \mathrm{r} = \frac{\mathrm{u}^2 v\rho}{RT} \text{.............} (17)$$

q= rate of cooling at constant volume.

$$\alpha = \left(1 - \frac{\mathrm{RT}}{\mathrm{u}^2 V\rho}\right)\frac{\mathrm{q}}{2\mathrm{u}} \text{............} (18)$$

The velocity of sound in air u is given as (Perry and Green 1997):

$$L_I = 10\log\left(\frac{4w - \frac{qw}{2u}\left(1-\frac{RT}{u^2 v\rho}\right)(4-Q)}{Iref\pi\ \mathrm{d}^2\frac{q}{2u}\left(1-\frac{RT}{uv\rho}\right)}\right) - \log\left(\frac{d_T}{d}\right)^2 \text{......}(19)$$

Substitute Equation 17 into 15 to obtain:

$$\mathit{But}\ \rho = \frac{\mathrm{M}}{\mathrm{V}}, \Rightarrow\ \rho\mathrm{V} = \mathrm{M} \text{.........} (20)$$

Substitute Equation 18 into equation 14 to obtain:

Substitute Equation 20 into Equation 19

If the initial wind (v m/s) blows in the direction of the sound then from assumption (vi), the resultant velocity of sound will be (u ± v), Equation 21 become:
v = wind speed (m/s)
M = mass of air (Kg)
u= velocity of sound in air (m/s)
T= temperature (ambient) (^{o}C)
R = specific gas constant
$\mathrm{d_T}$ = total distance (m)
d = distance stop length (m)
$\mathrm{I_{ref}}$= reference intensity = 10^{-9} Kw/m^2
q = rate of cooling at constant volume of the gas.

$$L_I = 10\log\left(\frac{4w - \frac{qw}{2u}\left(1 - \frac{RT}{u^2 M}\right)(4-Q)}{\mathrm{I_{ref}}\pi\, \mathrm{d}^2 \frac{q}{2u}\left(1 - \frac{RT}{u^2 M}\right)}\right) - \log\left(\frac{d_T}{d}\right) \text{.............} \quad (21)$$

$$L_I = 10\log\left[\frac{4\mathrm{w} - \frac{\mathrm{qw}}{2(\mathrm{u} \pm \mathrm{v})}\left(1 - \frac{RT}{(u \pm v)^2 M}\right)(4-\mathrm{Q})}{\mathrm{I_{ref}}\pi\, \mathrm{d}^2 \frac{q}{2(u \pm v)}\left(1 - \frac{RT}{(u \pm v)^2 M}\right)}\right] - \log\left(\frac{\mathrm{d_T}}{\mathrm{d}}\right) \text{.............} \quad (22)$$

Equation 22 is the modeling equation for the noise intensity level from the generator. Simulation of the model is obtained via computer programming.

4. Results

4.1 Experimental Results

Experimental results are presented in Tables 1 and 2.

Table 1. Results of noise intensity level (dB) measured for October 1997

Station	Noise intensity level (dB) at various distance (m)						
	20.0	40.0	60.0	100.0	200.0	500.0	1000.0
A	65.8	64.1	65.7	63.5	63.3	62.1	59.7
B	78.6	71.4	68.9	66.4	76.0	63.8	59.2
C	73.2	72.3	71.6	69.9	68.6	67.5	63.4
D	77.4	78.1	78.2	69.5	66.9	64.3	62.8
E	65.8	64.1	65.7	63.5	63.3	62.1	59.7
F	74.5	70.4	69.9	66.5	63.8	63.9	61.4
G	73.3	71.5	65.5	65.4	63.6	63.1	60.2

Table 2. Results of noise intensity level (dB) measured for November 1997

Station	Noise intensity level (dB) at various distances (m)						
	20.0	40.0	60.0	100.0	200.0	500.0	1000.0
A	66.8	67.9	67.7	66.8	63.8	62.0	63.5
B	81.0	72.0	69.0	70.0	67.0	62.0	60.0
C	71.9	68.3	67.8	68.2	64.0	62.6	61.3
D	77.4	75.9	80.1	65.9	66.3	64.7	58.9
E	66.8	67.9	67.7	66.8	63.8	62.0	63.5
F	78.6	73.4	68.5	65.5	63.1	60.5	60.5
G	77.9	71.8	67.6	67.7	61.9	61.0	60.2

4.2 Simulation Results

The model equation was programmed using Q-basic language. The results obtained at various ambient temperatures and wind speed is presented in Tables 3 and 4.

Table 3. Computed noise intensity level (dB) for various surrounding temperatures and wind speed of 2.5 m/s for 10,000 kW-power generator

Distance (m)	Temperature (K)					
	293.0	298.0	303.0	313.0	323.0	333.0
0.0	95.37327	95.37332	95,37337	95.37347	95.37357	95.37367
20.0	75.23184	75.23190	75.23195	75.23205	75.23215	75.23225
40.0	72.6088	72.60886	72.6089	72.609	72.60911	72.60921
60.0	71.07204	71.0721	71.07214	71.07224	71.07235	71.07245
80.0	69.98103	69.98109	69.98114	69.98124	69.98134	69.98145
100.0	69.13451	69.13456	69.13461	69.13471	69.13481	69.13492
200.0	66.50390	66.50395	66.50401	66.5041	66.50421	66.50431
300.0	64.96461	64.96467	64.96472	64.96482	64.96492	64.96503
400.0	63.87234	63.87239	63.87244	63.87265	63.87265	63.87275
500.0	63.02506	63.02511	63.02516	63.02526	63.02537	63.02547
600.0	62.33274	62.3328	62.33285	62.33295	62.3305	62.33315
700.0	61.74739	61.74744	61.74749	61.74759	61.74769	61.7478
800.0	61.24032	61.466	61.24024	61.25052	61.24062	61.24072
900.0	60.79304	60.79309	60.79314	60.79324	60.79335	60.79345
1000.0	60.39294	60.39299	60.39304	60.39314	60.39324	60.39334

Table 4: Computed noise intensity level (dB) for various surrounding temperatures and wind speed of 5 m/s for 10,000 kW-power generator

Distance (m)	Temperature (K)					
	293.0	298.0	303.0	313.0	323.0	333.0
0.0	95.35097	95.35065	95.35067	95.35077	95.35087	95.35098
20.0	75.20915	75.20921	75.20926	75.20936	75.20946	75.20956
40.0	72.58611	72.58616	72.58621	72.58631	72.58641	72.58691
60.0	71.04935	71.0494	71.04945	71.04955	71.04965	71.04975
80.0	69.95834	69.95839	69.95845	69.95855	69.95865	69.95875
100.0	69.11182	69.11186	69.11192	69.11201	69.11212	69.1222
200.0	66.48121	66.48126	66.48131	66.48141	66.48151	66.48161
300.0	64.94193	64.94197	64.94202	64.94213	64.94223	64.94233
400.0	63.84966	63.8497	63.84975	63.84985	63.84995	63.85006
500.0	63.00237	63.00242	63.00247	63.00257	63.00267	63.00277
600.0	62,31006	62.31001	62.31016	62.31026	62.31036	62.31046
700.0	61.7247	61.72475	61.7248	61.7249	61.72499	61.72509
800.0	61.21763	61.21768	61.21773	61.21783	61.21793	61.21803
900.0	60.77035	60.7704	60.77045	60.77055	60.77065	60.77075
1000.0	60.37024	60.37029	60.37044	60.37054	60.37054	60.37064

The objective of this project is to develop a mathematical model and computer simulation for the evaluation of noise radiated from generators. The noise radiated due to the variation of a generator during operation has adverse effects (physiological and psychological) on the inhabitants of the immediate environment. The noise pollution has however, lead to local problems in the immediate environment (Jackson *et al.*, 1989; Dix 1981).

Using the available experimental data of noise radiated at various distance of 20, 40, 60, 100, 200, 500, and 1000 m from the generator and that of simulated values as basis, it could be observed that the most dangerous zone from the generator is within 100-m distance from the generator (Fig.2). The effect of noise radiation felt within the distance range 0 – 100 m away from the generator is however dependent on the power of the generator, wind speeds, ambient temperature, etc. The experimental data presented in Tables 1 and 2 show that the noise intensity level varies from month to month and from station to station and the noise intensity decrease with distance away from the generator. The un-patterned nature of the experimental values could be attributed to the variation in the wind speed, ambient temperature, the load on the generator, etc. From the simulated results presented in Tables 3 and 4, the noise intensity varies directly with the distance away from generator (noise source). The noise intensity with distance away from generator also varies with the power of the machine. The higher the power of the machine (generator) the higher the noise intensity level radiated by the machine. Also, wind speed and ambient temperatures directly influence the intensity of radiated noise. Refraction of down wind sound waves toward the ground result in higher noise intensity than expected at a distance from the source (Blake and Mitchell 1972). Whereas, refraction of upwind sound wave occurs away from the ground causing acoustic shadows where theoretically no sound is heard (Thomas and Allen 1999). Excess alternation of about 20 to 30 dB within 50 m of the source at ground level may result from acoustic shadow. The effect of ambient temperatures on the noise radiated could be attributed to the fact that, in the summer, the ambient temperature decreases with height causing sound waves to be refracted away from the earth, while in the winter, due to temperature inversions, temperature decreases with height causing the noise intensity to be increased rather than attenuated (Gwendolyn *et al.*, 1993).

Comparison of experimental values with simulated results showed some variations from station to station with correlation coefficient ranging from 0.45 – 0.67. The noise radiation reduces as the distance from the generator increases (Fig. 2). The data of the present study indicate that the noise produced by the generators in the gas and flow stations in the Niger-Delta area is below the recommended limit by the World Health Organization (WHO) (Odigure 1999) with the range of 90 – 115 dB and duration of 8 to 0.25 hr exposure, respectively. Though exposure over a long period of time could cause serious problems in the environment.

The variation between experimental and modeling simulation results can be attributed to the following factors:

(i) The meteorological conditions, which are not constant throughout the season, make the experimental data have an un-patterned nature. These meteorological conditions such as atmospheric temperatures and wind speeds are not constant throughout the year, hence the result of noise intensity measured at one month varied from that measured in another different month.

(ii) The fluctuation in the power of the machine also, caused some of the assumptions made at the initial / conceptual stage of modeling such as direction of wind speed, temperature, pressure, and weather condition may not actually conform to prevailing atmospheric condition.

(iii) Experimental values are a measure of noise intensity for the prevailing meteorological conditions that are known to vary throughout the year. While the simulated results are instantaneous values, i.e. they measure the possible noise intensity that could be radiated by generator at specified conditions.

5. Conclusion

From this research, the following conclusions can be deduced:

1. The radiated noise propagation pattern is dependent on ambient temperate, nearness to the noise source (generator), wind speed, and the power of the generator.
2. The results of the computer simulation of the developed model show that the stronger the generator (in terms of power) the more noise it produces.
3. The effect of the noise is adversely felt within 100 m away from the generator.
4. Noise radiation from a generator in the area under study, is to some appreciable extent, conforming to the recommended limits set by the World Health Organization.

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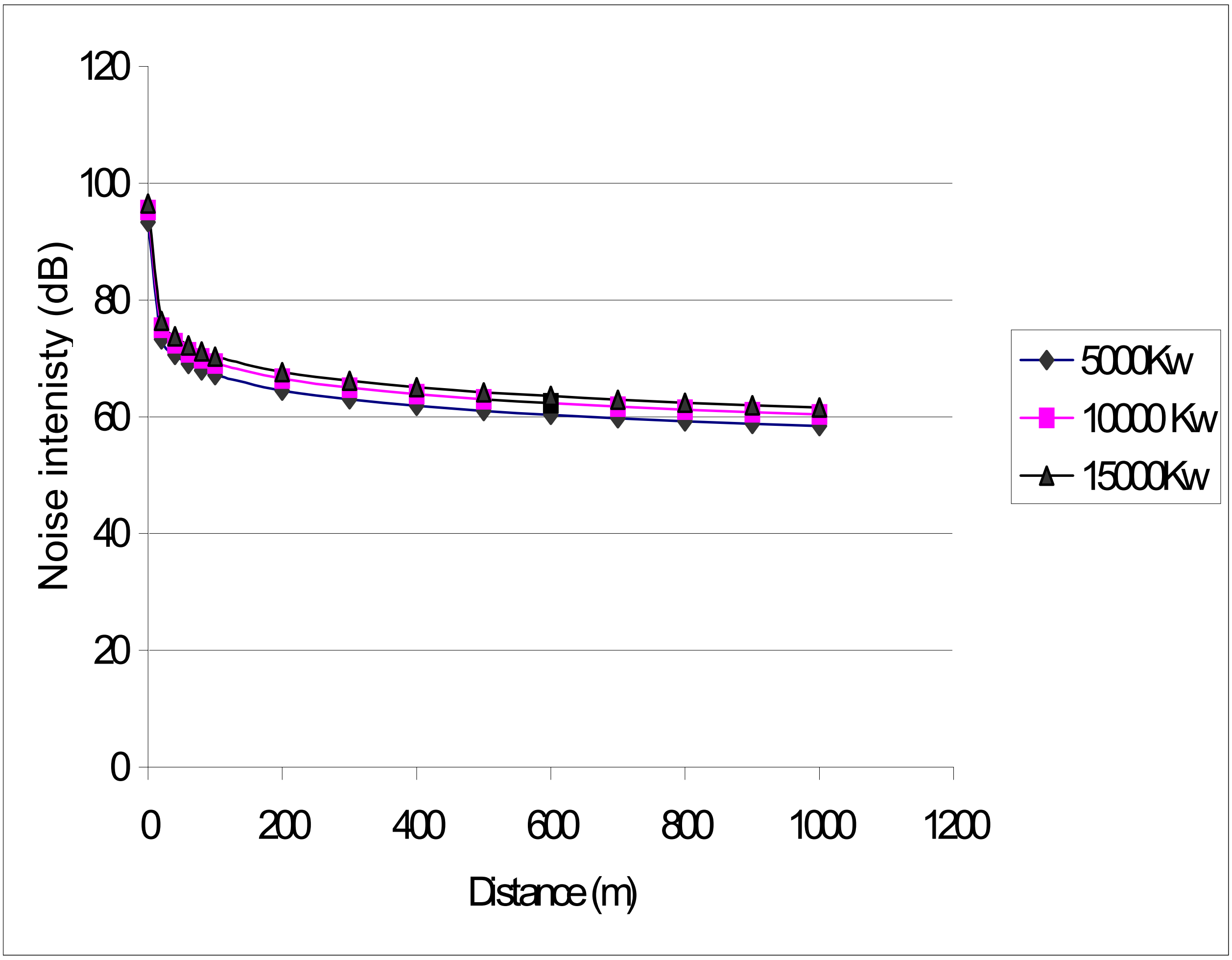

Fig. 2. Graph of noise intensity against distance at wind speed of 2.5 m/s and surrounding temperature of 313 K