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Evaluation of Effluent Gases from a Waste Incineration Plant: Case Study of a Medical Facility in Abia State, Nigeria.

Opara, C.C., Nwadike, M. C., Evbuomwan, B. O. and *Eniafe, B. O
Department of Chemical Engineering, University of Port Harcourt, Nigeria

Abstract — There are several environmental effects which have been traced to effluent gases from different sources. In this research, evaluation of effluent component gases and residual ash from a medical incinerator was carried out.Monitoring was conducted in two phases. The first phase lasted for about 20minutes which covered four different sampling points on the medical waste incinerator location. Second phase was the collection of fly ash from burnt medical waste to ascertain the concentration of lead (Pb)and cadmium (Cd) in it.Sampling was carried at 100m intervals for TPM10, CO2, NO2, SO2 and CO2emission from the facility and the results compared with an existing standard set by government regulatory agency (the Federal Ministry of Environment, Nigeria).The decision support system used statistical method and graphs as analytical tools to compare concentrations of effluent gases to standards. In addition, mathematical modelling of the gases, as they were dispersed from the medical waste incinerator were carried out using Gaussians model, Turner table and Sutton's dispersion model.The results showed excessive emissions of SO2and CO2above standards across 400m while TPM10, COand NO2 later fell below standard at 300m from the plant source. In addition, fly ash analyses of the waste confirmed the presence of heavy metals (lead and cadmium) at concentrations above standard.

Index Terms—: Effluent gases, heavy metals, pollution, medical waste, incinerator and dispersion model.

1 INTRODUCTION

Air quality, regarded as a main infrastructure element in solid waste management system is considered as a major criterion for human settlement.Increasing demand for residential, commercial and public use (hospitals, schools, offices) areas, along with the development of cities, has given rise to some environmental issues (Bell and Blake, 2000)

Incinerators as waste disposal facilities used to reduce trash and other types of waste to ashes (Sherry Holetzky, 2012). Medical waste incineration is an engineering process, which employs thermal decomposition that results in the reduction of mass by 70% and volume by 90% (Rao*et al.*, 1994; Stegemann*et al.*,, 1995; Grochowalski, 1998) and to destroy the organic fraction of the waste (Oppelt, 1987; Saxena and Jotshi, 1996; Penner, 1989). Medical waste incinerator utilizes high temperature to destroy medical waste products such as devices and supplies used to treat patients as well as biological waste such as blood or tissue and animal waste. The main benefit of using an incinerator to do away with medical waste is that the heat kills any potentially harmful and infectious disease causing organisms (microbes) which may be present in such wastes. This converts the waste materials into ash which is totally disinfected and safe for removal (evacuation) if needed.

Failure to properly dispose or destroy medical waste could be detrimental to public health. Blood, tissue, syringes, soiled materialsand other items disposed on the ground or water can pollute the environment posing threat to human life and animals. It can also cause obstruction of traffic which in addition destroys the aesthetic of the environment.

In addition, the invention of medical waste incinerator appears to be a shift from biological threat (infectious) to chemical threat (air pollution) to the environment. Medical waste incinerators are certainly capable of destroying bacteria and viruses; hence destroy the materials on which the pathogens are living (paper, cardboard, plastic, glass and metal). It is in this process that the acidic gases are generated (from the chlorinated organic plastics present), toxic metals are liberated (from the pigments and additives in the papers and plastic products as well as other items like batteries, discarded thermometers etc.), dioxins and furans are formed (from any chlorine present in the waste). None of these formidable chemical problems is inherent to the medical waste problemitself; instead, they all result from the supposed solution which is the medical waste incinerator (Connett, 1997).

Many hospitals simply dump all their waste together ranging from reception trash to operating room waste without any form of segregation and in most cases some of these hospitals use incinerators to treat their waste.

The problem of air pollution arising from medical waste incineration is a serious threat to environment in many cities of the world (Khitoliya2004 ;). High concentration level of pollutants (diozin, furan, hydrogen chloride gas, nitrogen oxides, sulphur

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oxides, carbon monoxide, particulate matter such as metal vapour like lead, cadmium) has been shown to have adverse effects on respiratory system (Pope and Dockery, 2006 and Ward and Ayres, 2004), cardiovascular and neurological systems in humans (Cramer, 2002,). These effects have been linked with a wide range of symptoms low birth weight (Ashdown – Lambert, 2005) increased hospitalization, sudden infant death and high mortality.

The amount and variety of waste materials have increased with the high growing rate of technology and population. Increased vehicular traffic and emission from incinerators and open dumps are the major contributors to air pollution and are matters of growing importance in many urban settlements. Normative limits and international guidelines indicate the maximum levels for number of individual pollutants in air samples. However, no restrictions have yet been given in many Nigerian cities. Municipals have often suffered from smoke emanating from refuse dumps and incinerators which makes air quality sometimes very poor (Elaigwuet al., 2007).

There are numerous human activities which release of toxic materials to the atmosphere. Industries are considered to be one of the potential known source that release toxic gases, fumes, vapours and particulate matters into the environment. The identity of these sources has been established in most cases but their quantitative importance is rarely determined (Elaigwuet*al.*, 2007).Okuo and Ndiokwere (2005) reported that in Warri (south-south, Nigeria), the major source of elemental pollution was due to re-entrained soil, automobile exhaust, residual oil combustion, petroleum activities, refuse burning and biomass incineration.

The Federal Environmental Protection Agency (FEPA) guideline is referred to as the principle Act by the amendment decree No. 59 of 1992, laws of the Federation of Nigeria. The agency is an integral part of the presidency and its mandate is to set a comprehensive national policy for the protection of the environment and conservation of national resources, including procedure for environmental impact assessment for all development projects (FEPA, 1991).

2 MATERIALS AND METHODS

2.1 Background

Measurement of the gases emitted from the medical waste incinerator at the source and ambient points at 100 metres intervals was carried out.
Direct interviews were conducted on some of the incinerator operators, resident doctors in the hospital and other workers to acquire more information.
Field measurementsconducted at the source (location of the medical waste incinerator) corroborates with the analysis of air quality in the ambient environment. The air pollutants readings were taken in the morning and in the evening to determine the difference in concentration of air pollutants.

2.2 Materials for Data Collection

Two different instruments were used to test for the gases. These are intrinsically safe digitalized gas detectors, uniquely designed to measure and display the concentration of the gases monitored.

The Crowcon Gasman, model CE-89/336/EEC was used to detect CO and NO_2 gases while Haz – dust, model HD-1000 was used to measured PM.

The Crowcon Gasman isplastic coated equipment with a design that allows the instrument to be used for almost all applications. The equipment has a sensor; saturated air conditions may prevent diffusion of the gas through the sintered flash back arrestor on the sensor housing due to build-up of moisture. Low battery condition is indicated by conditions such as sounder operation and no green LED light.

Air monitoring was conducted on the 21st of November, 2013, covering the medical waste incinerator located at a medical facility in Abia State. The first phase of the monitoring commenced at about 10:00am and lasted for about 20minutes. These covered four different sampling points on the same day. Afterwards; the fly ash from the burnt medical waste incineration was collected to ascertain the concentration of heavy metals in it.

Point 1

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The first point sampled was at source point of the medical incinerator plant.

Point 2
The second point sampled was at 100metres away from the medical waste incinerator plant. This continued till the fourth point at 400metres away from the plant.

2.2 Data Analysis Technique
The analysis is based on data collected from the different points in the study area. These data and results obtainedwere compared with already existing national standards and presented using Tables and Graphs.

3. RESULTS AND DISCUSSION

3.1 Background
Regarding the analysed air sampled of dispersed pollutants from the medical waste incinerator at 400m proximity from the plant measured at intervals of 100m showed a downward trend in concentration of the pollutants from the source point. In the Tables below, the observed trend of parameters studied shows that all the parameters decreased in concentration with distance away from the incinerator.
However, the atmospheric and meteorological conditions were strong and unstable and the corresponding stalk wind speed was taken from Tuner chart. Tables 1and 2 show the results of the monitored gases and heavy metals measured from the fly ash respectively. Stalk height was assumed to be 50m.

Table 1 Air Sample Analyses Result

Sampling Station	FMEnv Standard	Source Point	100m	200m	300m	400m
Total Particulate Matter (TPM10) ug/mg3	250.00	267.80	240.10	125.20	85.30	63.10
Carbon-monoxide (CO)(ppm)	10.00 — 20.00	35.00	28.00	20.00	16.00	13.00
Nitrogen(iv) Oxide (ppm)	0.04 — 0.06	1.36	1.20	0.85	0.45	0.20
Sulphur (iv) Oxide (ppm)	0.01	2.58	1.62	1.04	0.65	0.06
HCl (ppm)	50.30	15.00	12.54	11.74	8.18	5.63
Carbon (iv) Oxide (ppm)	250.00	722.00	686.00	660.00	548.00	520.00

Table 2: Fly Ash Analysis Result

Parameter	**FMEnv STD**	**Result**
Lead (ppm)	0.050	9.866
Cadmium	0.050	3.247

The dispersion models obtained from the experimental resultsare presented as follows:

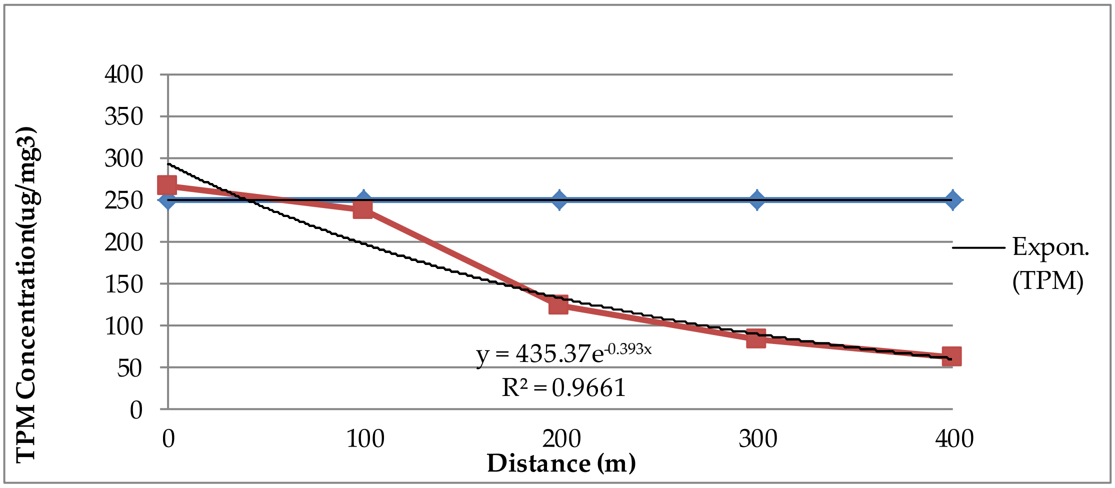

Fig.1: TPM_{10}Concentration Across Distances in Metres from Incinerator Compared to FEPA Standard.

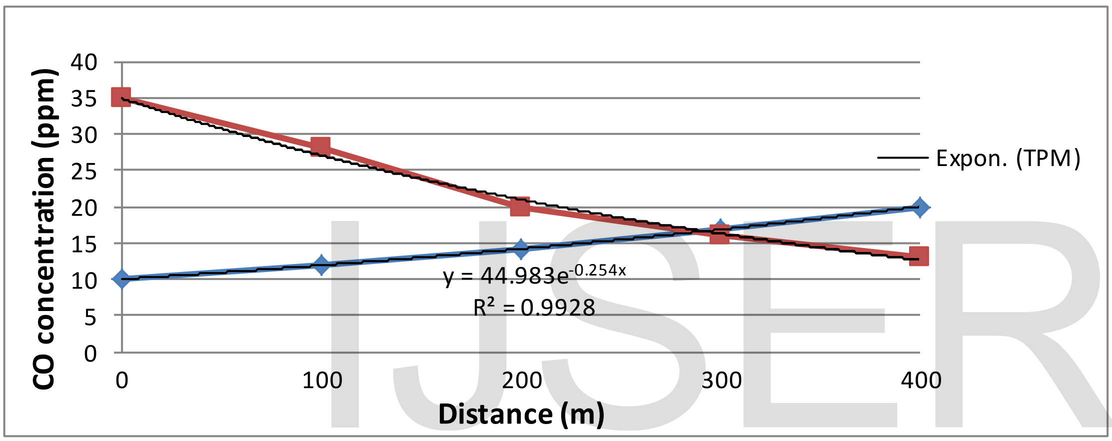

Fig.2: CO concentration across distances in metres from incinerator compared to FEPA standard

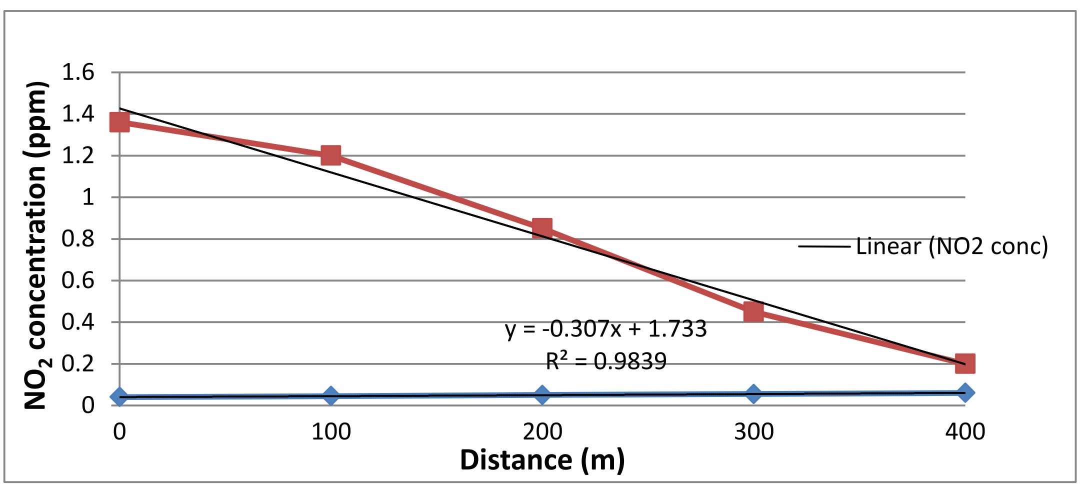

Fig.3:NO_2 concentration across distances in metres from incinerator compared to FEPA standard

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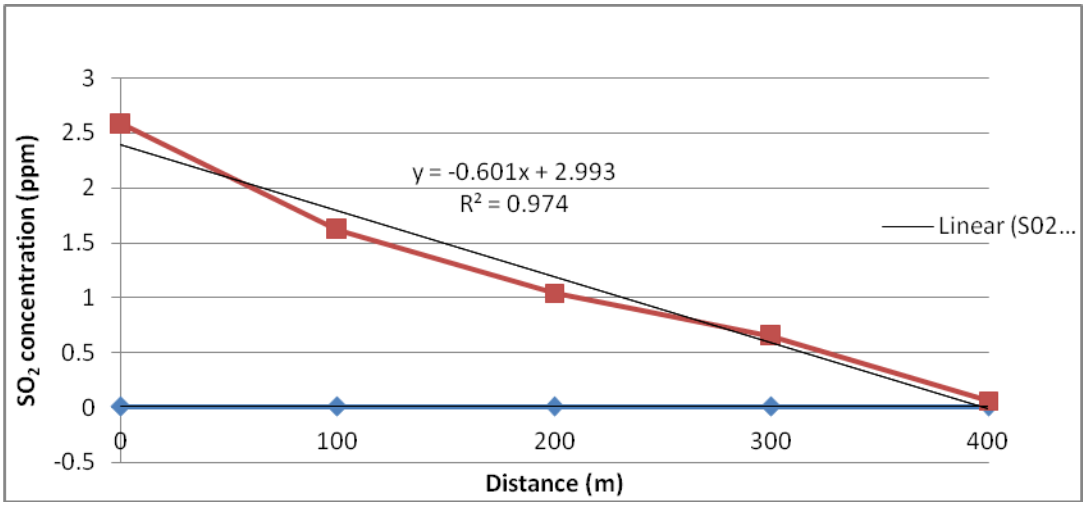

Fig.4: SO_2 concentration across distances in metres from incinerator compared to FEPA standard

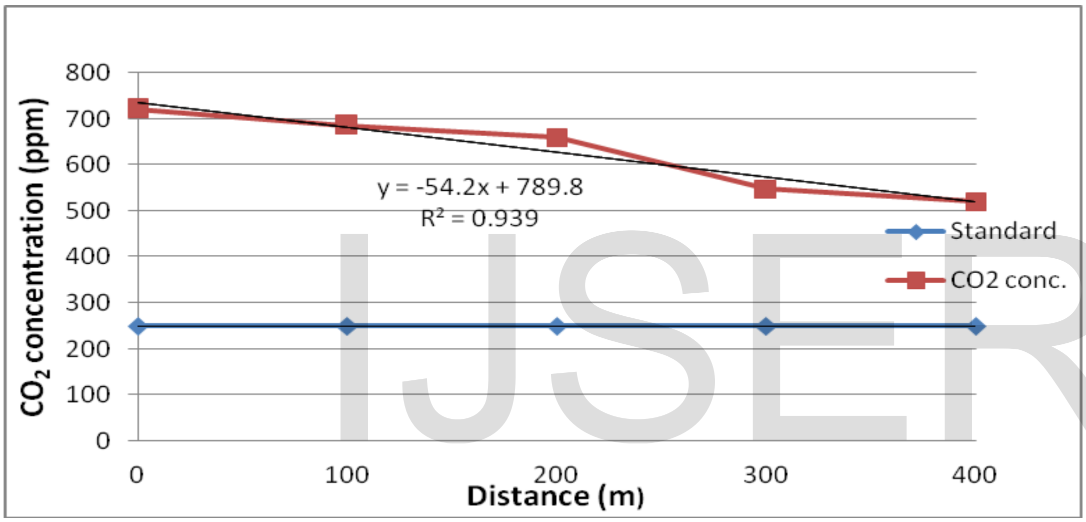

Fig.5: CO_2 concentration across distances in metres from incinerator compared to FEPA standard

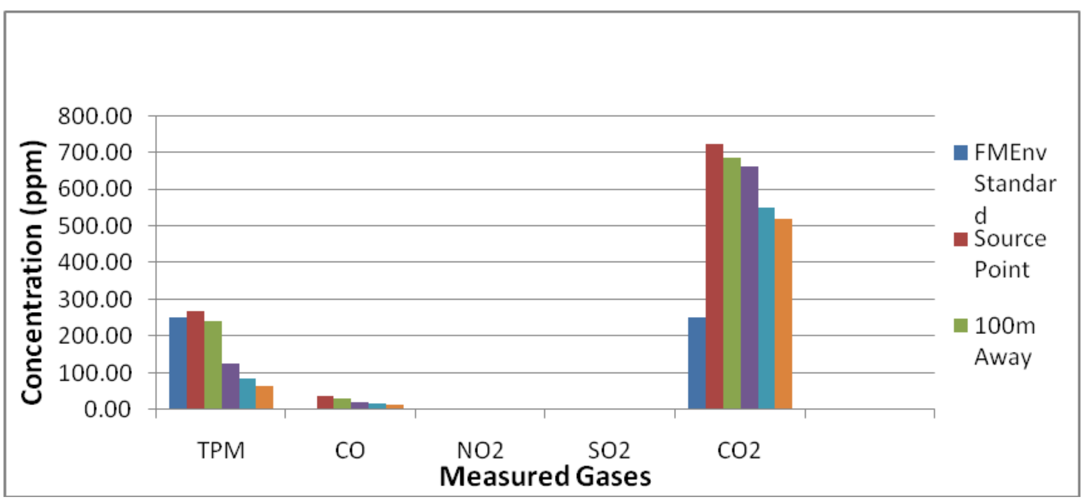

Fig.6: Chart showing the concentration of gases during incineration of a medical waste

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3.2 Mathematical Modelling of the Dispersed Gases fromthe Medical Waste Incinerator

Measurement of dispersion of gases from the medical waste incinerator under consideration was carried out on November 21, 2013 around 11am, being a sunny when the incoming solar radiation was strong and the air was unstable.Moderate wind at a stalk altitude was around 5-7m/s assuming average velocity of 6m/s at 10m level.

Wind speed was gotten through equation $u/u_1 = \left(H/z_1\right)^a$

Thus; U_1 = 6(10/50)0.25 = 4.01m/s

Table 3: Horizontal Dispersion Coefficient at Varying Distance

Class	A(metres)	x(metres)	Dy(metres)	Dy at varying distances(metres)			
				100	200	300	400
A	0.4	250	58.33	23.33	46.67	70	93.33
B	0.295	1000	150.94	15.09	30.18	45.74	60.38
C	0.2	1000	102.34	10.23	20.46	30.7	40.94
D	0.13	1000	66.52	6.65	13.3	19.96	26.61
E	0.098	1000	50.14	5.01	10.02	15.96	20.02

Table 4: Vertical Dispersion Coefficient at Varying Distance

Class	**B(metres)**	**x(metres)**	**P**	**D_z(metres)**	**D_z at varying distances(metres)**			
					100	**200**	**300**	**400**
A	0.125	250	1.03	36.88	14.75	29.5	44.26	59.01
B	0.119	1000	0.986	108.03	10.8	21.61	32.41	43
C	0.111	1000	0.911	60.02	6	12	18.01	24.01
D	0.105	1000	0.825	31.78	3.18	6.36	9.53	12.71
E	0.100	1000	0.778	21.58	2.16	4.32	6.47	8.63

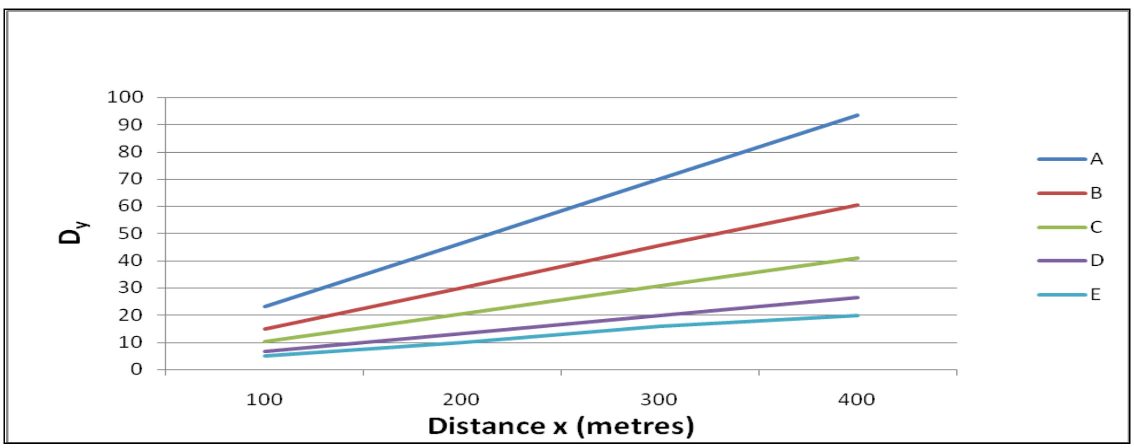

Fig.7: Mathematical model of horizontal plume standard deviation at varying distances (x)

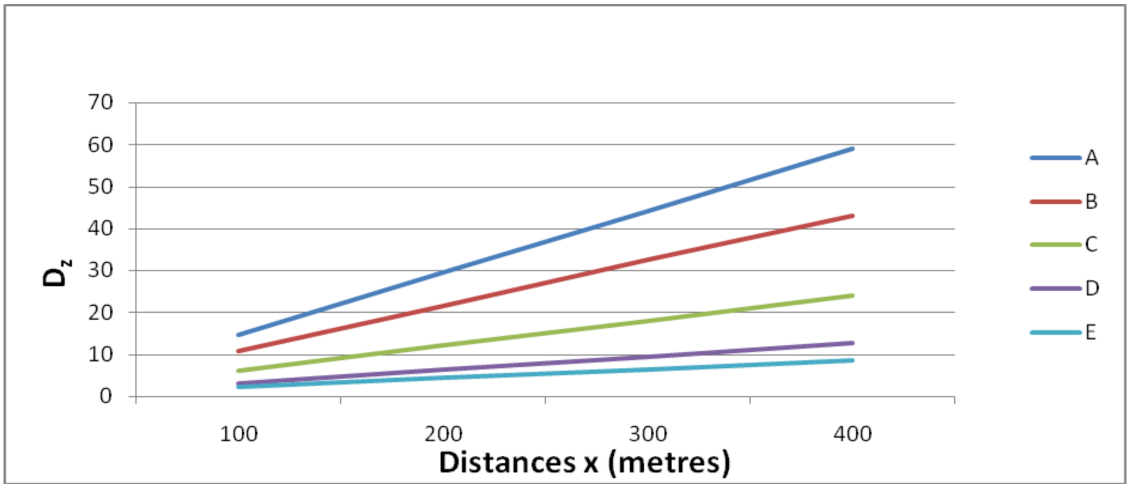

Fig.8: Mathematical Dispersion Model of Vertical Plume Standard Deviation at Varying Distances (x)

3.3 Sutton's Diffusion Parameters

From statistical theory of turbulence, Sutton developed expression for D_y and D_z in terms of the diffusion parameters $C_y$andC_z. and the turbulence index n[1]. The expression is given by;

$$D_y = \sqrt{1/2}C_y X^{(2-n)/2} \text{ ......(1)}$$

$$D_z = \sqrt{1/2}C_z X^{(2-n)/2} \text{ ......(2)}$$

The diffusion parametersC_y andC_z depend on components of turbulence in the y and zdirections, respectively and is determined in practice by fitting the diffusion equation to concentration profile data. The turbulence index, n' depends on wind velocity profile equation and it is related to exponent (α) alpha;

$$\alpha = \frac{n'}{(2-n')} \text{ ...... (3)}$$

where;

α = 0.25 on unstable condition, thus n' is given by;

$$n' = 2\alpha/(1+\alpha) \text{ ......(4)}$$

Substituting for, α = 0.25 into Equation (4) gives n' = 0.4

Assuming the C_y and$C_z$represent values of the horizontal and vertical turbulent dispersion coefficients at varying distance of 100m intervals in Tables 1and 2 respectively, Sutton diffusion parameters can be formulated using Equations1 and 2 respectively

However, our interest is only on Equation 2, recalling it and substituting the variables gives us Table 5.

$$D_z = \sqrt{1/2}C_z X^{(2-n)/2}$$

The First 100m of class A can be formulated for D_z

When n' = 0.4, X = 100, C_z = 14.75.Thus, repeating for the rest at various distance of X and C_z given Table 5

Table 5: Resultsfrom Computation of D_z Using Sutton's Diffusion Parameters

Class	D_z(metres)	$C_z$at varying distances(metres)				Suttons D_z (metres)			
		100	200	300	400	100	200	300	400
A	36.88	14.75	29.5	44.26	59.01	504.02	1059.17	3000.50	5034.83
B	108.03	10.8	21.61	32.41	59.01	415.22	830.44	2199.16	3687.37
C	60.02	6.00	12	18.01	24.01	168.90	588.15	1220.94	2048.92
D	31.78	3.18	6.36	9.53	12.71	89.52	311.72	646.06	1084.62
E	21.58	2.16	4.32	6.47	8.63	60.80	211.75	438.62	736.45

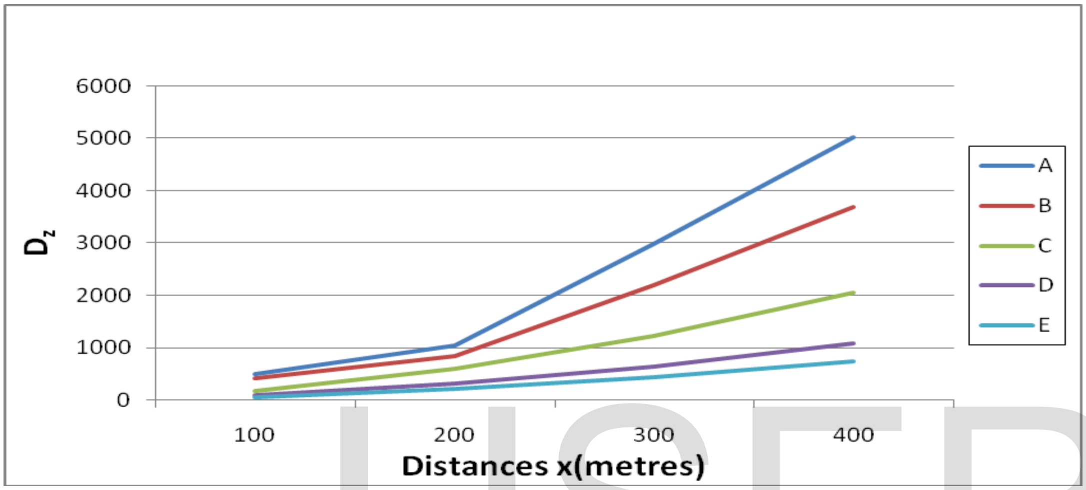

Fig 9: Sutton Model of Spreading Coefficient D_z at Varying Distances.

The analysis of air samples of the medical waste incinerator (case study) was carried out at 11a.m. on November21, 2014on a sunny day under unstable air and strong incoming solar radiation. The moderate wind speed at the stalk altitude was assumed to be 6m/s based on Turner table. With it, the surface wind speed was calculated to be 4.01m/s, which fell within 3-5 wind speed range and class B of Turner table.
Thus, with the surface wind speed and constants(A, B and P) in Equations1 and 2 whose figures appeared on Turner table, the horizontal and vertical standard deviation of plume at distance x were calculated as shown in Tables 3 and 4 respectively. Hence, the mathematical models for the dispersion of gases from a medical waste incinerator were plotted as a function of downwind distance. Figures 7, 8 and 9 respectively display the mathematical model of horizontal and vertical plume standard deviation at varying distance (x) and Sutton's dispersion model respectively.
However, result of the sampling for the concentration of pollutants ($TPM_{10,}$ CO, SO_2 NO_2 and CO_2) at 100meter intervals showed that total particulate matter (TPM_{10}) concentration exceeded the set standard only at source point and decreased below standard across 100m away. Similarly, Carbon monoxide (CO) concentration exceeded standard at source and 100maway but fall within the standard range at 100m downward.

However, the concentration of Sulphur (IV) Oxide (SO_2), Nitrogen (IV) Oxide (NO_2) and Carbon
Dioxide (CO_2) was observed to be above standard even at 400m from the plant source. This may be probably attributed to the fact that that the medical waste generated at the Medical Facility under consideration at Umuahia, Abia State, and Nigeria may contains more of Nitrogen, Carbon and Sulphur elements.
Furthermore, the analysis of the fly ash collected after the incineration showed that the ash contained heavy metal (Cadmium and Lead) at concentrated exceeding set standards (regulatory limits).

4 APPENDIX

4.1 LIST

TABLE 6
TABLE FOR SYMBOL AND ITS DEFINITION

Symbols	Definition
α	Constant (Alpha), 0.25 on unstable and 0.5 on Stable
A,B and P	Constants with values give on Turners Table
Cyand Cz	Concentration profile data in y and z directions respectively
Dy	Vertical standard deviation of the plume in at distance x
Dz	Horizontal standard deviation of the plume in at distance x
H	Height of the plume centre line
ń	Turbulence index
P(A)	Concentration of pollutant A
Π	Constant 22/7
Q	Source Strength
√	Square root
x	Distance in horizontal direction
U	Average wind speed
U1	Surface wind speed measure at z_1=10m

5 CONCLUSION

Concentration of effluent gases obtained from the medical facility under consideration were analysed and results showed excessive emission rates.

Sampling was carried out at 100m intervals for TPM_{10}, CO, NO_2, SO_2 and CO_2 on the facility under study and result showed excessive emission of$NO_2$and SO_2 above set standards across 400m while TPM_{10}, CO and CO_2 later fell below standard at 300m from the plant. In addition, fly ash analyses showed that the medical waste contained lead and cadmium at concentrations above standard limits.

Mathematical model of the gases were carried out using Gaussians model and Turner table to determine the vertical and horizontal standard deviations of the plume at specified distances (x) from source which are functions of downwind distance.

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