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Heavy Metal and Air Quality Assessment around a Healthcare Waste Incinerator Facility in Nigeria

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Abstract: Waste incineration represents a prominent waste treatment strategy applied towards the treatment of hospital waste in many developing countries. Adequate pollution control limits the exposure of waste workers and the community to toxic contaminants in air emissions and ash. This study examined the air quality emissions of acid gases (Nitric Oxide, Sulphur Oxides, Hydrogen Sulphides, Ammonia, Carbon Monoxide, Methane) using a portable Haz-Dust Particulate detection system. Determination of heavy metals (Cadmuim, Chromium, Cobalt, Copper, Nickel, Iron, Lead, Magnesium, Manganese and Zinc) released in the flu ash samples in the neighboring environments at the front and back of the incinerator, including the electrical station and school block around the Federal Government College, Keffi was measured using an Atomic Absorption Spectrophotometer (*iCE* 3000 series). The results showed that the particulate emissions were in the range of 0.10-0.26 (mg/m^3). Carbon monoxide levels detected were in the range of 5-12 ppm. The distribution of acid gases ranged between 0.01-0.07 (ppm) for CO, SO_2, NH_3, H_2S and NO_2. No measureable concentrations of Chromium, Copper and Lead was detected. The concentrations of Iron (0.202 mg/l) and Magnesium (18.309 mg/l) were below the WHO acceptable limits while Cobalt (0.171 mg/l), Nickel (3.466 mg/l), Manganese (3.589 mg/l) and Zinc (10.61 mg/l) were higher than approved limits. Improvements are required for the medical waste incinerator in this study by integrating addition process treatment systems to reduce environmental pollutants being released.

Keywords: Medical Waste, Incinerators, Particulate Emissions, Heavy Metals

1. Introduction

Healthcare waste possess an array of hazardous and non-hazardous streams of discarded materials, emanating from diagnosis, treatment, manufacture or laboratory testing of biomedical related products. The distribution of such waste types ranges from R&D research facilities, primary healthcare centers, blood banks, dental clinics, medical laboratories and hospitals, the latter accounting for the bulk of generated waste material [1].

Proper disposal of the large volumes of healthcare waste possess a significant environmental and health challenge whereby the risk of disease transmission amongst sanitation officials, health workers, patients and the general community is high. The advent of such exposure if further worsened by the possible emergence of new disease agents arising from the amalgamation of mixed biomedical wastes.

A decade ago, hospitals and biomedical research/non-research laboratories were not considered to be disposing of their healthcare wastes in an environmentally responsible manner given that they were not equipped with the right technical tools [2]. A critical part of medical waste management approaches includes chemical, biological, irradiation and thermal treatment for which thermal treatment at varied temperatures, including incineration, represents the most common treatment options available [3]. Incineration and higher thermal treatment in excess of 750°C results in the incomplete combustion in the air emissions and ash due to chemical and physical changes to the waste material [4].

Open burning and incineration without adequate pollution control expose waste workers and the community to toxic contaminants in air emissions and ash. Incineration plants emit an assortment of pollutants to the atmosphere. These include but are not limited to particulate matter, heavy metals (arsenic, cadmium, chromium, copper, mercury, manganese, nickel, lead, etc.); acid gases (hydrogen chloride, hydrogen fluoride, sulfur dioxides, nitrogen oxides), oxides of nitrogen, carbon monoxide, organics and various other materials present in medical wastes, such as pathogens, cytotoxins, and radioactive diagnostic materials [5]. As a precautionary measure, it has been suggested that gas scrubbers and other flue gas cleaning systems be integrated into incineration plants in a bid to curb the pollutant load released to the atmosphere [6].

The result of which is the dreaded public exposure to infectious waste from dysfunctional treatment plants. Likewise, epidemiological reports culminating from medical waste incinerator emissions in high income countries have suggested a link between cancer, leukemia and all types of tumors among adolescents residing near such incinerators [7]. In the United Kingdom, a study indicated that a distinctive relationship exists between reproductive or developmental disorders, specifically spina bifida, heart defects and anacephalus healthcare waste incineration [8].

Nigeria like many other low to middle income countries across Africa, Asia, the Middle East and Southern America, examined for their healthcare waste management practices is confronted with large volumes of healthcare waste coupled with antediluvian incinerators which in some instances do not meet international standards [9-10]. The Federal Medical Centre Keffi, located in Nassarawa state of Nigeria, latitude 4^0 15' 40'' N and 4^0 20' 10'' N; and longitude 5^0 25' 55'' E and 5^0 35' 05'' E is one healthcare facility that has upgraded its waste treatment facility from a manual incineration plant to a rotary kiln automated incinerator donated by the Ecological Fund office of Nigeria. In light of the deleterious health effects of high concentrations of flue ash or heavy metals on humans, animals and plants, which includes inhibition of enzyme functions, deterioration of the immune system, interference with neural transmission signaling, diminished fitness levels, interruption of cell division and normal reproductive functionality, etc [11]. It is therefore essential to monitor and assess environmental exposure of the harmful effluents emanating from such medical waste incinerators. The overall aim of this study was determine the heavy metal concentration from the flue ash generated by incineration and compare values obtained with WHO and the Federal Ministry of Environment standards.

2. Materials and Methods

The study was conducted at the Federal Medical Centre, Keffi, Nigeria with a bed capacity of almost 1400. The Primary data for this research work was generated directly from the effluent samples obtained post incineration of the medical waste. Calculation of the heavy metal concentration/physiochemical properties of the flue ash and air quality analysis of the immediate or surrounding environment where the incinerator is installed was also performed. Sampling of air quality was conducted at ten (10) random sampling points, thirty (30) minute walk per sample point within the premises of the Federal Medical center using a Gasman Crowcon instrument. The heavy metal concentration of about 10 heavy metals were determined using Atomic Absorption Spectrophotometer. Data collection was done from August to October 2015.

2.1. Air Quality Analysis

Pollutants analyzed and measured included NO_2, SO_2, CO, H_2S, NH_3, CH_4 O_2 and SPM. Temperature, relative humidity and noise were equally measured for the environment. Particulate matter was measured using a portable Haz-Dust Particulate detection system via infrared electromagnetic radiation to sense airborne particles. The sensing method is traditionally referred to as near forward light scattering. The mass concentration readout is expressed in milligrams per cubic meter (mg/m^3).

2.2. Heavy Metal Analysis

The heavy metal concentrations present in the flu ash samples were analyzed using an AAS (Atomic Absorption Spectrophotometer, *iCE* 3000 series) fitted with D_2 lamp for background correction. Air-acetylene flame was used for corrected concentrations (mg/l) and the selected elements were Pb, Cd, Mn, Cu, Fe, Zn, Ni, Mg, Co and Cr. 4ml of 6 M HCl, was added to the crucible containing the flue ash. It was ensured that all ash comes into contact with the acid. The crucible with the content was placed on a hot plate with heating control which was allowed to heat up to about 300°C to evaporate the acid. When it was done, the crucible was removed from the hot plate and allowed to cool. After cooling, the residue was dissolved in 20 ml, of 0.1 M HNO_3. The crucible was swirled with care so that all ash comes into contact with acid. It was covered with watch glass and let stand for 2 h. Then, the solution in the crucible was thoroughly stirred with stirring rod and filtered using Whatman No. 42 filter paper. The content was transferred into a 100 ml well-labeled polyethylene bottle prior to analysis [12]. This procedure was carried out in triplicate and the amounts of trace metals were recorded as mean value. The extracts were analyzed for heavy metals using AAS.

2.3. Statistical Methods

Mean and standard deviation were used to determine the variation in the per capita waste generation amongst the different units in the Federal Medical Centre Keffi, Nassarawa state, Nigeria.

3. Results

3.1. Air Quality Analysis of Incinerator Pollutants

Six of the seven distinctive gas emissions tested from the

different sampling points in this study were detected at varying concentrations in comparison with the acceptable limits given by the federal ministry of environment (Table 1). Notable emission included carbon monoxide with detected levels ranging from 3-12 (ppm), sulphur dioxide; 0.01-0.08 (ppm) and nitric oxide whose detected levels ranged between 0.01-0.06 (ppm).

Particulate pollution, resulting from the inadvertent release of dioxins as a result of *de novo* synthesis of carbon, hydrogen, oxygen, chlorine and a range of volatile substances in the form of exhaust gases was detected (Table 1). Particulate matter measurements revealed much higher levels at the back of the incinerator (0.28 Mg/M^3) in comparison to the front (0.27 Mg/M^3) has the highest recorded levels from all tested sites (Table 1).

3.2. Heavy Metal Concentration Generated by the Incinerator

The mineral content of the flu ash samples depicted (Table 2) revealed that Magnesium was the highest detected element (18.309 ± 0.55Mg/L) and Cadmium was found as the lowest concentration (0.046 ± 0.35Mg/L), while the remaining elements detected in the order Zn > Mn > Fe > Co > Cd. Chromium, Copper and Lead were not detected in samples (Table 2). The concentrations of these elements were above and below the acceptable limits for minerals that are useful for human and animal health.

4. Discussion

Incineration is the adopted strategy for waste treatment across most industrial sectors in West Africa as an effective treatment strategy that reduces the overall volume of waste whilst destroying pathogens, other organic and inorganic pollutants. However, negative correlations with this treatment method is its environmental impact via the direct release of effluents such as flu ash amongst other gaseous emissions which has several public health implications [13], [24-25]. Emulating developing countries in their selection and improvement of technology applications as it impacts on the environment, monitoring the environmental effects of appropriate technologies is crucial for developing countries. Like many developed countries where incineration of healthcare waste is the norm, the incomplete destruction of metallic pollutants is easily encountered whereby such waste streams become concentrated and deposited as bottom ash and emitted into the atmosphere [4].

As a result of this, almost all hospital waste incinerators contain a much higher concentration of heavy metals in their bottom ash than the environs. If proper disposal is not effected, these concentrated pollutants leach out where they pose severe health risk to humans upon ingesting of plants or animals whereby these heavy metals would have been bio-accumulated [14]. A study revealed that upon entry into the human body, these heavy metals at concentrated levels impede normal enzyme functions, compromises immuno-defensive abilities, inhibits neural transmission signaling, triggers commotion towards normal cell division which results in the development of carcinomas, production of reactive oxygen species, reproductive disorders, etc [11]. All these factors warrant the early, routine assessment of air quality and heavy metal concentration around a healthcare waste incinerator. In this study, the carbon monoxide emissions during the waste treatment process at either side of the incinerator was higher (12ppm each) than that of the Nigerian healthcare waste guideline (Table 1). The increased particulate emissions could be as a result of partial oxidation of the waste stream. Also exceeding the acceptable limits where measurements taken from the federal medical centre's (11ppm) main gate and the administrative block by the federal government college (11ppm). Prolonged exposure to carbon monoxide is likely to increase the commencement of heart disease to the populace dwelling close to the incinerator site. Oxides of sulphur dioxide and nitrogen are also likely to trigger respiratory complications. In general, emission readings obtained in this study from the ten different points in and around the medical waste incinerator for nitric oxide and ammonia was within the acceptable limits ≤0.06ppm. The readings obtained for hydrogen sulphide in front of the incinerator (0.07ppm) and main electrical station (0.06ppm) exceed the permitted limits and call be linked to construction materials used in the build [15]. Overall, incinerator in this study is functionally useful but could be improved via the integration of a multi-stage combustion chamber and scrubber which both aids in the mopping up of excess fumes as well as prompts complete combustion of waste at higher temperatures. Heavy metal analysis revealed that only iron (0.202 mg/l) and magnesium (18.309 mg/l) were detected and below the WHO permissible limit of 0.3 (mg/l) and 150.0 (mg/l) respectively (Table 2). Data obtained also revealed that chromium, copper and lead were not detected in any of the samples obtained. The non-detection of certain heavy metals does not however imply that the flue ash generated from the incineration of the medical waste does not contain these three heavy metals which could have undergone leaching thereby validating suggestions by other researchers [16].

Table 1. *Air quality analysis of incinerator pollutants.*

S/No.	LOCATION	TIME	GEOGRAPHIC LOCATION	TIMING	TEMPERATURE (°C)	PARTICULATE (Mg/M^3)
1	Front of Incinerator	02:00pm	ELEVATION 291m N 08^0 50′42.3″ E 007^0 53′10.9″	Before	34.6	0.17
				During	32.6	0.27
2	Back of Incinerator	02:09pm	ELEVATION 297m N 08^0 50′42.1″ E 007^0 53′11.3″	Before	32.7	0.19
				During	31.7	0.28

S/No.	LOCATION	TIME	GEOGRAPHIC LOCATION	TIMING	TEMPERATURE (°C)	PARTICULATE (Mg/M^3)
3	Main Unit Electrical Station	02:18pm	ELEVATION 303m N 08^0 50′44.1″ E 007^0 53′11.8″	Before	31.8	0.13
				During	33.8	0.26
4	Audit Block of FMC Keffi	02:28pm	ELEVATION 305m N 08^0 50′44.3″ E 007^0 53′07.3″	Before	32.3	0.11
				During	30.3	0.25
5	School of Health Technology Keffi	02:37pm	ELEVATION 302m N 08^0 50′41.3″ E 007^0 53′04.4″	Before	33.6	0.12
				During	30.6	0.18
6	FMC Keffi Ward	02:47pm	ELEVATION 294m N 08^0 50′46.8″ E 007^0 53′05.6″	Before	32.1	0.1
				During	31.1	0.16
7	FMC Keffi Main Gate	02:57pm	ELEVATION 303m N 08^0 50′50.3″ E 007^0 53′03.03″	Before	34.7	0.13
				During	33.7	0.2
8	FGC Keffi Gate	3:15pm	ELEVATION 296m N 08^0 50′55.6″ E 007^0 53′17.5″	Before	33.1	0.11
				During	31.1	0.17
9	Adjacent to Admin Blk FGC Keffi	3:50pm	ELEVATION 294m N 08^0 50′42.3″ E 007^0 53′13.7″	Before	31.9	0.2
				During	32.9	0.26
10	Front of Physics Lab FGC Keffi	04:00pm	ELEVATION 305m N 08^0 50′39.7″ E 007^0 53′13.0″	Before	34.5	0.15
				During	32.5	0.23
11	Allowed Limits	-	-			0.25

Table 1. *Continued.*

S/No.	CH_4 (ppm)	CO (ppm)	SO_2 (ppm)	NH_3 (ppm)	H_2S (ppm)	O_2 (ppm)	NO_2 (ppm)
1	ND	8	0.01	0.01	0.07	20.8	0.01
		12	0.08	0.03	0.01	20.8	0.06
2	ND	8	0.01	0	0.01	20.8	0.02
		12	0.08	0.03	0.01	20.8	0.03
3	ND	5	0.01	0	0.06	20.8	0.01
		9	0.07	0.01	0.01	20.8	0.03
4	ND	4	0.01	0	0.04	20.8	0.02
	ND	7	0.07	0.01	0	20.8	0.02
5		4	0.01	0	0.03	20.8	0.03
	ND	6	0.06	0.02	0	20.8	0.02
6		3	0.01	0	0.02	20.8	0.01
	ND	6	0.06	0.01	0	20.8	0.01
7		5	0.01	0	0.03	20.8	0.03
	ND	11	0.06	0.01	0	20.8	0.03
8	ND	4	0.04	0.01	0	20.8	0.04
		9	0.06	0.01	0	20.8	0.02
9	ND	6	0.04	0.01	0.01	20.8	0.04
		11	0.06	0.02	0.01	20.8	0.05
10	ND	5	0.04	0.01	0.01	20.8	0.04
	ND	10	0.06	0.02	0.01	20.8	0.03
11	0	10	0.01	0.03	0.01	21	0.06

Key: FMC = Federal Medical Centre, FGC = Federal Government College

Table 2. *Heavy Metals detected in the flu ash.*

Heavy metals	N = items (10 samples)	Mean Conc. of metal (Mg/L)	Std Dev	WHO allowable limits (Mg/L)
Cadmium (Cd)	10	0.046	0.35	0.003
Chromium (Cr)	10	-	-	0.050
Cobalt (Co)	10	0.171	0.45	0.005
Copper (Cu)	10	-	-	2.000
Nickel (Ni)	10	3.466		0.070
Iron (Fe)	10	0.202	0.75	0.300
Lead (Pb)	10	-		0.010
Magnesium (Mg)	10	18.309	0.55	150.000
Manganese (Mn)	10	3.589	0.15	0.4000
Zinc (Zn)	10	10.610	0.25	3.000

The detectable heavy metals within the flu ash revealed cadmium (0.046 mg/l) which is over ten times the WHO acceptable limit (Table 2), the result of which can lead to lung, kidney and bone poisoning, coupled with the advent of bronchitis and toxemia in the liver [17], [26]. Although within certain quantities, zinc is found in the environment and is an essential element for man, animal, plant and microbial life, at elevated levels, it becomes a contaminant as exposure to large amounts of this element may lead to anemia, impairment of the pancreas as well as a reduction in the levels of high-density lipoprotein (HDL) cholesterol [18]. The data revealed that the manganese concentration was at 3.589 (mg/l), representing almost nine times higher than the acceptable limits. While manganese is an essential micronutrient for all life forms, its release to the atmosphere, especially as particulate matter would lead to impairment of the lungs, nervous and reproductive systems among other organs [19]. The elevated levels of Zinc in the flu ash samples have been considered to be due to the rich concentration of metal alloys from such elements utilized in the fabrication of medical items [20].

The assortment of heavy metals discharged from medical incinerators include cadmium, cobalt, nickel and manganese among others, all of which were detected in this study at concentrations 0.171mg/l, 3.466 mg/l and 0.202 mg/l respectively, above the WHO limits [21]. The high concentrations of Cadmium, Cobalt, Nickel, Iron and Zinc obtained in this study appear similar to the findings in a recent report which evaluated a medical waste incinerator [22]. These compounds are highly leachable and would stay continuously active when flushed into the soil [23].

5. Conclusion

Data obtained in this study has shown that the discharge from the target medical waste incinerator released particulate emissions in the range of 0.1-0.28 mg/m^3, carbon dioxide (5-12 ppm), SO_2 (0.01-0.08ppm) and H_2S (0.01-0.07ppm). the flu ash samples contained varying concentrations of heavy metals outside the approved WHO limits; Cadmium, Cobalt, Nickel, Manganese and Zinc. Long term usage of such an incinerator may lead to higher risks of exposure of waste management workers, community health workers and the population living close or around the waste incinerator to harmful toxins over time. Failure to meet approved Federal Environmental and WHO limits suggests that treatment facilities should be integrated with additional processing facilities that produces less fumes and residual heavy metals. Epidemiological studies to characterize the population exposure to establish toxicological data and geo-accumulation indexing to improve our current knowledge base and proffer solutions that aid the treatment process. The current location where the incineration is sited within the premises of the Federal Medical Centre very close to the perimeter fence of the Federal Government College Keffi poses very high risk to both human beings and environment. Therefore, plans should be put in place to move the incinerator out of the Hospital premises to a safer location.

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