Vol. 14(10), pp. 311-328, October 2020
DOI: 10.5897/AJEST2020.2882
Article Number: 1833B5764870
ISSN: 1996-0786

http://www.academicjournals.org/AJEST

African Journal of Environmental Science and Technology

Full Length Research Paper

Assessment of air pollutant emissions from healthcare waste incinerators of different design features

Anicetus Honest[1]*, Samwel Manyele[2], Josephat Saria[3] and Julius Mbuna[4]

[1]Ministry of Health, Community Development, Gender, Elderly and Children, P. O. Box 743, Dodoma, Tanzania.
[2]Department of Chemical and Mining Engineering, University of Dar es Salaam, P. O. Box 35131, Dar es Salaam, Tanzania.
[3]Department of Environmental Studies, The Open University of Tanzania, P. O. Box 23409, Dar es Salaam, Tanzania.
[4]Dar es Salaam College of Education, P. O. Box Private Bag, Dar es Salaam, Tanzania.

Received 9 July, 2020; Accepted 11 August, 2020

The aim of this paper was to e valuate the levels of gaseous emissions from four different healthcare wastes incinerators in three regional hospitals and one national hospital in Dar es Salaam, Tanzania. The incinerators studied differ in terms of capacity (kg/h) and design features. Five gaseous air pollutants (CO, CO_2, NO_x, and SO_2) were analyzed in the sampled flue gases using a portable desktop combustion gas analyzer (model KANE900 Plus). About 29, 30, 34 and 40 consecutive runs were conducted for each incinerator at Amana, Temeke, Mwananyamala, and Muhimbili National Hospital (MNH), respectively. Other properties of the flue gas analyzed include temperature (FT), combustion efficiency (CE), percent excess air, and CO/CO_2 ratio. Results showed lower CE range (lowest at Ilala regional hospital (51.4%) and highest at MNH (60.0%). The highest flue temperature was detected at MNH (911°C). The CE and pollutants concentration increased with FT and decreased with percent excess air. Results indicated poor performance of the incinerators, due to higher gaseous emissions above US-EPA standards, putting communities around these hospitals at occupational and public health risks. Installation of various air pollution control devices (APCDs) as well as monitoring and inspection programs is strongly recommended.

Key words: Incinerator, combustion efficiency, healthcare waste, flue gas, acidic gaseous emissions, excess air, flue gas temperature.

INTRODUCTION

Of all the available technologies for disposal of healthcare waste, incineration has been found to be the most effective method overall for destroying infectious and toxic material, in the healthcare waste stream with high volume and weight reduction (Singh and Prakash, 2007). However, poor performance of incinerators may result into release of many toxic substances necessitating research. According to World Health Organization (WHO,

*Corresponding author. E-mail: hanicetus@gmail.com. Tel: +255 754311115.

2014), healthcare waste is defined as any waste, which consists wholly or partly of human and animal tissue, blood or any other body fluids, excretions, drugs or pharmaceutical products, swabs or dressings, syringes, needles or sharp instruments, being waste which unless rendered safe may prove hazardous to any person coming into contact with it (Baharun et al., 2005; Manyele and Anicetus, 2006; Manyele and Mujuni, 2010). Hazardous waste is treated almost exclusively by incineration. Incineration must be understood as an element of comprehensive logistics for the treatment of those wastes which due to their harmful nature have to be managed separately from municipal waste. Hazardous waste is waste requiring particular supervision, which by its nature, condition or amount poses a particular hazard to health, air and/or water pollution (Gitonga, 2017). Currently, there is a rapid increase in the use of incineration and burning structures, especially in healthcare waste instead of landfilling as means of disposal of healthcare waste in Tanzania and elsewhere. Incinerators are widely used due to their waste volume and weight reduction potential, and efficacy in destroying pathogens and toxic chemicals in the waste (ICRC, 2011). Another advantage is the ability of incineration method to suit most types of waste. These incinerators are however, known to release good number of toxic chemicals into the atmosphere as well as to produce ashes and other solid waste residues. Undesirable health effects due to mass burn incineration of healthcare waste are of great concern as large population groups and workers may be exposed to the emitted toxic substances (WHO, 2018). Many of these substances such as dioxins, and heavy metals are known to be persistent, bioaccumulative, carcinogenic or endocrine disruptors. Waste generated by healthcare activities includes a broad range of materials from used needles and syringes to soiled dressings, hypodermic needles, intravenous set needles, broken vials and ampoules, dressings, bandages, gauze, and cotton contaminated with blood or other body fluids; and many other including diagnostic samples from laboratories and mixed or absolute chemicals (World Bank, 1999; Gitonga, 2017; Manyele and Anicetus, 2006).

Incineration is a waste treatment process that involves combustion of organic substances contained in waste materials (Batterman, 2004). Incineration of waste materials converts the waste into ash, flue gas, and heat. The ash is mostly formed by the inorganic constituents of the waste, and may take the form of solid lumps or particulate matter (PM) carried by the flue gas (Wiles and Shepherd, 1999). The flue gases must be cleaned of gaseous and particulate pollutants before they are dispersed into atmosphere. In some cases, the heat generated by incineration can be used to generate electric power or heat the water for use in the hospital (Batterman, 2004), leading to energy saving.

In several countries, there are still concerns about the environmental impact of incinerator wastes (Batterman, 2004). Many of these incinerator wastes especially from poor countries were built few decades ago and did not include systems for materials separation to remove hazardous, bulky or recyclable materials before combustion (Batterman, 2004; Manyele et al., 2011). These facilities tend to risk the health of the community around due to inadequate levels of gas cleaning and combustion process control (Batterman, 2004).

To minimize the hazards, incineration of healthcare waste is a significant alternative way for disposal of this category of waste. Emissions of heavy metals and organic pollutants from these facilities cause significant environmental harm (Anamul et al., 2012). People living near incinerators are similar to those living near landfill sites or dump sites in which they are potentially exposed to chemicals by way of inhalation of contaminated air, consumption of contaminated foods, water or dermal contact with contaminated soil (Allsopp et al., 2001). Incinerator operators can also be occupationally exposed to chemicals emitted from incinerators, which are generally of higher intensity and duration compared with environmental exposures; quantitative levels of compounds can be more easily ascertained and defined. According to Goren et al. (1999) determination of occupational exposure to the general population needs care since workers differ from the general population in terms of sex, age, and lifestyle, and are also self-selected to be relatively healthy (healthy worker effect).

Tanzania like many other developing countries still faces the problem of healthcare waste management (HCWM). The unsafe disposal of health-care waste (for example, contaminated syringes and needles) poses public health risks (Baharun et al*.,* 2005; Manyele and Mujuni, 2010). Contaminated needles and syringes represent a particular threat as the failure to dispose of them safely may lead to dangerous recycling and repackaging, which lead to unsafe reuse. Contaminated injection equipment may be scavenged from waste collection and storage areas and dumpsites and either are reused or sold to be used again (Ferronato and Torretta, 2019).

The use of healthcare waste incinerators appears to be rapidly expanding in developing countries whereas it discharges hundreds of pollutants into atmosphere (Ferronato and Torretta, 2019). Many of these chemicals are both toxic and bio accumulative, building up over time in the body in an insidious fashion with the risk of chronic effects at much lower exposures (Takata, 2003). In Tanzania, very little attention has been paid to the concentrations of the major chemicals emitted in an effort to avoid acute local toxic effects.

The combustion process in the incinerator is an exothermic reaction between organic matter in the waste acting as a fuel and oxygen. During incineration process, the fuel is predominantly waste loaded and the oxygen source is air. During this process of combustion, many of

the end products are stable whether the material burned is healthcare waste, municipal solid waste, natural gas, coal, gasoline, wood or hazardous waste (Hettiarachchi et al., 2018). The flame zone in the incinerator is sufficiently hot to break down all organic and many inorganic molecules, allowing reactions between most volatile components of the waste and the oxygen and nitrogen in air. Because the dominant element is carbon and hydrogen, therefore the predominant reactions are between carbon and oxygen, producing carbon dioxide (CO_2), and between hydrogen and oxygen, producing water vapor. When there is insufficient air supply, incomplete combustion of organic compounds in the waste feed stream produces some carbon monoxide and carbon-containing particles. Hydrogen also reacts with organically-bound chlorine to produce hydrogen chloride (HCl). In addition, many other reactions occur, producing sulfur oxides (SO_x) from sulfur compounds, nitrogen oxides (NO_x) from nitrogen compounds (and, a little, from the nitrogen in the air), metal oxides from compounds of some metals, and metallic vapors such as mercury and lead (Wiedinmyer et al., 2014).

The exact composition of emissions from incinerators will vary with type of waste loaded at given time, the efficiency of the installation and the pollution control measures in place (Takata, 2003). During incineration more toxic forms of some of heavy metals and man-made organic chemicals can be created. The three most important constituents of the emissions, in terms of health effects, are particulates, heavy metals, and combustion products of man-made chemicals (Wiedinmyer et al., 2014). The latter two can be adsorbed onto the smaller particulates making them especially hazardous. In Tanzania, most hospitals had low incineration capacity, with few of them made of fire brick and other refractory materials (Baharun et al., 2005; Manyele and Anicetus, 2006). On the other hand, poor management of healthcare waste potentially exposes health care workers, waste handlers, patients and the community at large to infection, toxic effects and injuries, and risks of polluting the environment. It is essential that all healthcare waste materials are segregated at the point of generation, appropriately treated and disposed of safely (WHO, 2011). The United States Environmental Protection Agency (US-EPA) recommended standards for CO, SO_2, and NO_x are 97.9, 88.1 and 411.2 mg/m^3, respectively.

Over the last three decades there has been increasing global concern over the public health impacts attributed to environmental pollution, in particular, the global burden of disease. The World Health Organization (WHO, 2014) estimated that about a quarter of the diseases facing mankind today occur due to prolonged exposure to environmental pollution. Most of these environment-related diseases are, however, not easily detected and may be acquired during childhood and manifested later in adulthood due to long latency periods of toxins in the human body.

The impact of waste incinerators on health and their releases of hazardous combustion products, such as dioxins and PAHs are of great public concern (Ernesto and Savino, 2019). Research has identified numerous toxic compounds, which are emitted in stack gases and in ashes, as well as many unidentified substances of unknown toxicity (Ardevol et al., 1999). Individuals who are exposed to the hazardous substances resulting from incineration, and whose health can, therefore, be potentially affected by such exposure, include workers connected with incinerator facilities and populations living within their local vicinity.

The potential effects of metals and other pollutants that are very persistent in the environment may extend well beyond the area close to the incinerator. Persistent pollutants can be carried long distances from their emission sources, go through various chemical and physical transformations, and pass numerous times through soil, water or food. Dioxins, furans, and mercury are examples of persistent pollutants for which incinerators have contributed a substantial portion of the total national emissions (Parry and Stevens, 2001).

Persistent air pollutants, such as dioxins, furans and mercury, can be dispersed over large regions well beyond the local areas and even the countries from which the sources first emanate. Food contaminated near an incineration facility might be consumed by people close to the facility or far away from it. Thus, local deposition on food might result in some exposure of populations at great distances, due to transport of food to the markets. However, distant populations are likely to be more exposed through long-range transport of pollutants and low-level, widespread deposition on food crops at locations remote from the incineration facility (Demirezen and Aksoy, 2006).

Waste products resulting from incineration take the form of stack gas emissions to the atmosphere, bottom ashes (slag) and fly ashes (caught in filters in the incinerator stack) which ultimately are disposed of to landfill sites. Where water is used for cleaning processes in an incinerator, there are also releases of waste products to water (Allsopp et al., 2001), which is easier to manage than when emitted into atmosphere such systems include water operated wet scrubbers.

The weight and volume of the original raw waste are normally reduced during incineration. It is often stated that the solid residues (ashes) remaining are less than one quarter to one-tenth of the initial weight of the raw waste (Pluss et al., 1991; Matee and Manyele, 2015a) and volume reduction of about 90-95% is achieved (Pluss et al., 1991; Baharun et al., 2005). Higher weight reduction of up to 94.6% has been reported (Matee and Manyele, 2015a). If the entire pollutants load in the output from an incinerator is summed up, then the output will exceed the original waste input in terms of mg/kg, indicating that the pollutants become concentrated in the

small volume or weight of ashes. This is true for heavy metals, which would otherwise be widely spread in the environment. Given the small amount of ashes generated, it is easy to control the pollutants (Matee and Manyele, 2015a).

The gases present in the stack result from the combination of carbon-based materials with oxygen and are usually ignored in calculating the mass of residues. The combination with oxygen to form CO_2 increases actual weight of the gas. Aeration during incineration also contributes to the volume of flue gas. Residues from wet gas cleaning systems can generate appreciable volumes of contaminated water and solids. However, the resulting liquid waste can be easily controlled than when the pollutants are dispersed into atmosphere (Enviros Consulting Ltd., 2004). In the case of the statistic concerning volume reduction, this is usually generated by reference to the volume of un-compacted wastes (Pluss et al., 1991). However, experience based on handling HCW, will support the volume reduction concept. Landfilled municipal solid waste MSW, however, is generally compacted to increase stability and prevent water infiltration as well as reduce the volume of the wastes. Such compaction is, however, minimal compared to volume and weight reduction via generation of ashes after combustion incineration (Wiles and Shepherd, 1999).

The exact nature of the substances released during incineration depends on the composition of the waste that is incinerated. For instance, incineration of chlorinated organic compounds will cause the formation of hydrogen chloride (HCl) and this in turn can contribute to the formation of dioxins (Allsopp et al., 2001). Technical standards that are applied both to the incineration process and to pollution control equipment will also influence the final products of incineration (Oppelt, 1987). However, whatever control technology is applied, all types of incineration result in releases of toxic substances in ashes and in the form of gases and particulate matter. It is also ascertained that the products of compounds that contain sulfur, nitrogen and halogens have a potential effect on human health and the environment. Specific compounds of concern which are generated include CO, NO_x, SO_x, and HCl.

Nitrogen oxides, sulphur dioxide and carbon monoxide are among pollutants emitted from incinerators. Apart from contribution to the formation of ozone and acidic aerosols, the oxides of nitrogen and sulphur dioxide are associated with respiratory short-term effects especially in individuals with a particular susceptibility (Goren et al., 1999). Carbon monoxide is likely to increase the onset of heart disease.

According to Baharun et al. (2005), for the perfect working incinerator the combustion efficiency is assured by operating the secondary combustion chamber at temperature ≥ 1000°C at the same time maintaining an oxygen rich environment. The burners will re-ignite the partial products of combustion emitted from the primary chamber and raise the temperature of the gases in the excess of 1000°C (Matee and Manyele, 2015b). Baharun et al. (2005) indicated that the combustion efficiency in the secondary chamber is necessary to minimize emissions of byproducts of incomplete combustion and is capable of achieving combustion efficiency of up to 99.99% if the temperature is ≥ 1000°C. The combustion air is supplied by the fan controlled to maintain an oxygen level of not less than 7% (Baharun et al., 2005).

The aim of the present work was to evaluate the levels of emissions of four healthcare waste incinerators in four hospitals (Ilala Regional Hospital, Temeke Regional Hospital, Mwananyamala Regional Hospital, and MNH) all of which are in Dar es Salaam Region. Five air pollutants (CO, CO_2, NO_x, and SO_2) were sampled and analyzed in the emissions. Further analysis involved experimental determination of CE expressed as a percentage and CO/CO_2 ratio.

MATERIALS AND METHODS

Sample collection sites

The study was conducted at three municipal regional hospitals (Ilala, Temeke and Mwananyamala) and one National Hospital (MNH). All these hospitals have double-chamber high-tech incinerator. In this type of incinerator, there are two burners of similar specifications, the primary and secondary combustion chamber. The chambers' fire-walls are made of refractory bricks, with secondary chambers about 1/3 of the primary chambers in size. The primary and secondary chambers for Temeke Hospital incinerator are supplied with excess air from a 1.1 kW blower, while all other incinerators use burners with high blowing capacity. According to Manyele et al. (2011), the burners at Temeke Hospital are made to use 7 L of oil per cycle and are designed to return the un-used oil to the tank. The specification of the burners: Rielo 40 G series, 230 V, 50 Hz, capacity of 95-213 kW, and fuel maximum viscosity is 6 mm^2/s at 20°C are fitted on both chambers and able to burn waste at high temperature more than 1000°C. The control panel contains all switches for timer, primary burner, blower, and temperature displays. Healthcare waste was collected from different sections of the hospital and weighed. The healthcare waste was loaded manually after identifying the content in the waste. The incinerated materials were not sorted and contain mostly pampers, gloves, needles, infusion, swabs, packing materials, syringes, blood, paper, and drugs remains. The wastes were then mixed in the primary chamber in order to facilitate good combustion followed by tightly closing the loading door ready to start combustion. The incineration time was set and the secondary burner switched on in order to pre-heat the chamber up to a temperature of about 250 to 300°C, followed by switching on the primary burner and air blower.

Determination of gaseous emissions

The gaseous emissions concentration from incinerator stack was determined using a portable desktop combustion gas analyzer type KANE900 Plus manufactured by KANE International Limited, UK. The combustion gas analyzer undergoes automatic calibration once switched ON by pumping in fresh air into the sensors to allow toxic sensors to be set to zero and the oxygen sensor to be set to 20.9% or above, which is normally found in ambient air. As per combustion

analyzer emission measuring specifications, the sampling hole should be located and drilled at the length of two times the internal diameter (ID) of the stack from the incinerator chimney or where the stack starts which was almost 2 ft from the base of the stuck. Also the probe with thermocouple (temperature detecting sensor with a range from 0 to 1200°C) was connected to the analyzer and then inserted to the drilled hole at the center of the stack or exhaust diameter. The hole measures 17 mm. The analyzer established the air composition characteristics in combustion exhaust/stack by recording the proportions of oxygen (%O_2), and carbon dioxide (%CO_2), carbon monoxide (CO in mg/m^3), nitrogen oxides (NO_x in mg/m^3), sulfur dioxide (SO_2 in mg/m^3), carbon monoxide/carbon dioxide ratio (CO/CO_2). It also determines flue and ambient temperatures (FT and AT in °C), excess air (X Air in %), combustion efficiency (CE in %), and draft (mbar) reading time or residence time. The combustion efficiency, describes how good or poor fuel (mostly hydrocarbon) is burning in the presence of oxygen, producing carbon dioxide and water.

RESULTS AND DISCUSSION

Design features and performance of incinerators studies

Table 1 shows the design features in capacity and maximum observed temperatures of the incinerators in different hospitals.

Table 1 indicates the type and capacity of the incinerators operated in the study area and the highest temperature observed during the study. The highest was Incinerator at MNH with a temperature of 914°C and the lowest was Ilala with a temperature of 711°C. Only one (1) (MNH incinerator) operated earlier required temperature of 850°C and above. This indicates that majority 75% of incinerator operate below required standard of 850°C. In this study, the maximum combustion efficiency was detected at MNH state average, that is, 65.9% and the lowest was at Mwananyamala Regional Hospital with CE of 54.2%.

In developed countries operation of the incinerators is governed by regulating board, such that to qualify for a process of the thermal treatment of healthcare waste, that possess infectious and non-infectious properties, requires that the temperature of the flue gas, measured near the inside wall of the combustion chamber, after the last air supply is at least 850°C for the non-infectious waste, and at least 1100°C for the waste with the infectious properties (Wajs et al., 2019). This temperature must be maintained for at least two seconds, even under the most adverse conditions (for example unstable work of the burners). This is not the case for the present study as the highest temperature was detected at MNH with 914°C followed by Temeke Regional Hospital with 842°C, Mwananyamala Regional Hospital 792°C and the lowest was at Ilala Regional Hospital with 711°C. The results observed concur with the values obtained earlier where the average maximum temperatures achieved in the primary chamber was 397.8 and 839°C for secondary chamber. These temperatures were lower compared to the design temperatures of 850 and 950°C as a result of loading wet waste. The healthcare waste materials from these hospitals are characteristically heterogeneous. Its material composition is diverse hence these lower temperatures observed indicate poor performance, which may lead to release of toxic gases harmful to community residing near the incinerator.

Temperature is a key factor to the emissions of NO_x and SO_2 as well as CO and CO_2. The results in this study showed that high temperature leads to high NO_x concentration while low temperature corresponding with low concentration of NO_x (Figures 2 and 3). At the beginning of reaction, the bottom of gasifier exits a dense phase area with sufficient oxygen where fuel was burned sufficiently and nitrogen in the fuel can be oxidized easily, whereas in the upper thin phase area NO_x did not have proper reductive reaction condition. Especially, without plenty of reductive radical of OH and CH, which results in more production of NO in a short time, the maximum amount of NO_x reached approximate 632 mg/m^3 at Mwananyamala Regional Referral Hospital. Subsequently, the concentration of NO_x decreased and run to stable due to formation of NO_x. It can be predicted that higher temperature prefers NO_x forming and lower temperature may restrain its production.

Temperature profile during incineration and emission testing

Figure 1 shows the flue gas temperature profiles during emissions testing for the four incinerators.

The Figure 1 shows trend and performance of the four incinerator temperature observed during the study in different run. The highest (914°C) observed temperature was at MNH followed by Temeke Regional Referral Hospital (842°C), Mwananyamala Regional Referral Hospital (792°C) and the lowest was at Ilala Regional Hospital Incinerator (711°C). The normal required incinerator temperature is between 850 and 1100°C. Matee and Manyele (2015b) studied the temperature profiles in the primary and secondary chambers of the MNH incinerator, which were observed to increase to the maximum peak value before dropping again.

Combustion efficiency of incinerators

Combustion efficiency, defined as the ratio of heat released by the fuel (healthcare waste in this case) to the heat input by the fuel. Combustion efficiency is affected by type and composition of waste loaded into the incinerator (sharps waste, pathological waste, pharmaceutical waste, blood bags, etc.), bed temperature, air or gas flow rate, and excess air levels. Combustion efficiency increases with fuel volatile matter content and bed temperature, and decreases with increasing superficial gas velocity. Combustion efficiency initially

Table 1. Description of hospital incinerators.

Name of facility	No. of beds	Waste generation rate (kg/day)	Type of incinerator	Combustion design	Capacity (kg/h)	Observed max. temperature (°C)
MNH	1500	325	Diesel burner operated	Vertical Double Chamber	100	914
Mwananyamala Regional Hospital	210	299	Diesel burner operated	Horizontal-Double Chamber	80	792
Ilala Regional Hospital	170	143.4	Diesel burner operated	Horizontal Double Chamber	80	711
Temeke Regional Hospital	190	232	Diesel burner operated	Horizontal Double Chamber	150	842

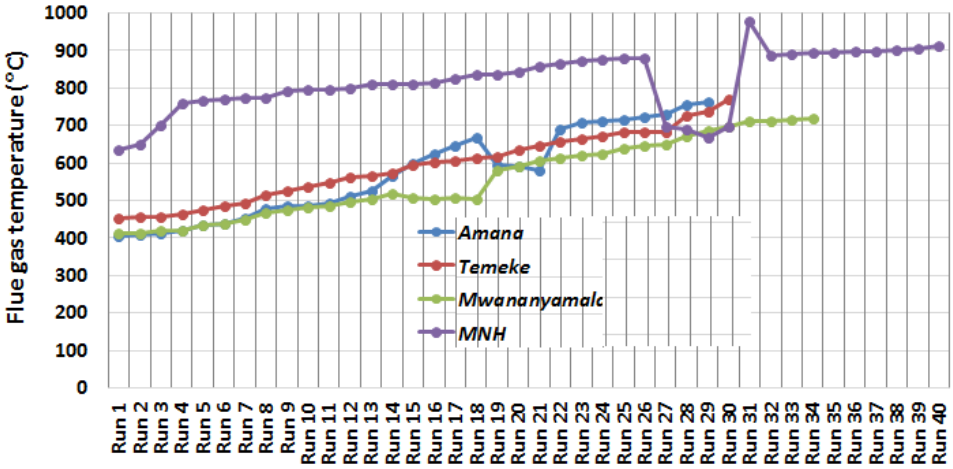

Figure 1. Flue gas temperature during emission testing in the four incinerators.

increases with increasing excess air level and then decreases. This is believed to be due to an increase in CO and hydrocarbon emissions as the excess air level increases to higher levels. Table 2

Combustion efficiency is a measurement of how well the fuel being burned is being utilized in the combustion process. This is different from the efficiency number produced on the analyzer, which is reflective of the total amount of heat available from the fuel minus the losses from the gasses going up the stack. The combustion efficiency calculation considers both the stack temperature and the net heat and moisture losses. Figure 2 shows the effect of incineration temperature/based on the flue gas temperature in the secondary chamber on combustion efficiency for the four incinerators studied. In general, CE increases with increasing temperature.

The CE data from Temeke shows two different linear relationships with flue gas temperature for the intervals from 400 to 600 and 600 to 800°C, the latter having at higher CE values (Figure 2). On the other hand, data from MNH shows increasingly higher values from 600 to 1000°C.

The linear dependency of CE on temperature of the flue gas was approximated by a generalized Equation 1 with $R^2 = 0.899$.

$$y = 0.037x + 30.278 \quad (1)$$

Pollutants concentration profiles for different acid gaseous pollutants in the incinerator flue gas

Profiles of carbon monoxide, CO

Carbon monoxide emissions result when carbon in the waste is not oxidized to carbon dioxide (CO_2). High levels of CO indicate that the combustion gases were not held at a sufficiently high temperature in the presence of

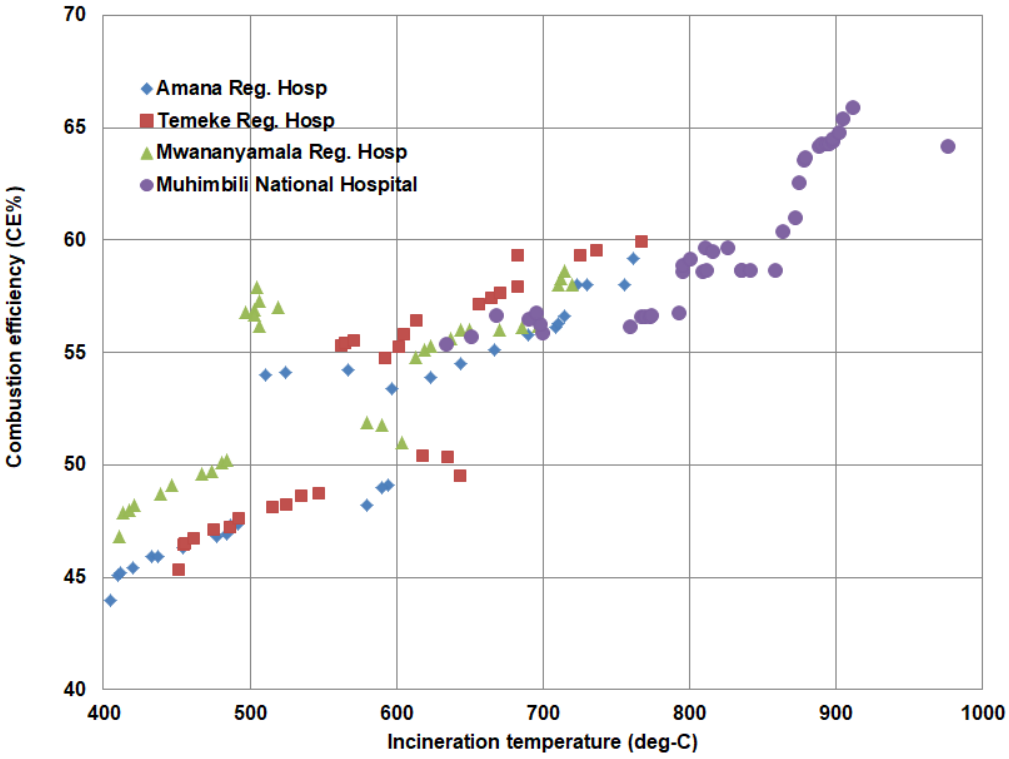

Figure 2. Comparison of performance of incinerator at Amana, Mwananyamala and Temeke regional hospitals and MN.

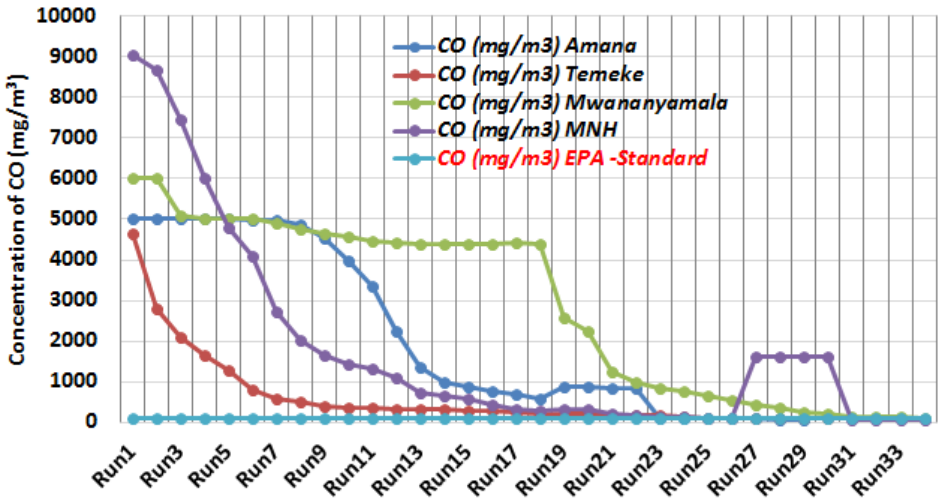

Figure 3. Levels of carbon monoxide concentration in the flue gas during test runs for the different incinerators.

oxygen (O_2) for a long enough time to convert CO to CO_2. Because O_2 levels and air distributions vary among combustor types, CO levels also vary among combustor types. Carbon monoxide concentration is a good indicator of combustion efficiency, and is an important criterion for indicating instabilities and non-uniformities in the combustion process (Baharun et al., 2005).

The greater the amount of air present and the higher degree of turbulence, the less CO will be formed. Unfortunately, turbulence as a combustion parameter

Table 2. Average values of combustion efficiency and temperature in different incinerators.

Statistics	Amana Reg. Hospital		Temeke Reg. Hospital		Mwananyamala Reg. Hospital		Muhimbili National Hospital	
	FT (ºC)	CE (%)	FT (ºC)	CE (%)	FT (ºC)	CE (%)	FT (ºC)	CE (%)
Minimum	405	44.0	452	45.3	411	46.8	634	55.4
Mean	572.5	51.4	589.6	53	555.8	52.3	815.5	60
Maximum	762	59.2	768	59.9	720	58	911	65.9
Std. dev.	119.4	5.0	91.3	5.0	103.3	9.7	81.5	3.4

cannot be easily quantified. Hence, only the amount of air present (indicated by the amount of O_2 emitted), and the combustion temperatures affecting the equilibrium constant and the relationship of CO and CO_2 produced is being considered.

During the incineration of municipal solid waste (MSW) in incinerators, the carbon monoxide is formed as the product of incomplete combustion. CO is an indicator substance for the combustion process and an important quality criterion for the level of combustion of the gases. As a rule, CO is measured continuously in the plants. Average CO emissions, as daily means, are below 50 mg/m^3. Plants reflecting best available techniques (BAT) have daily means in the range of <10 mg/m^3 (Wang, 2002).

Generation of CO is due to limited air supply and temperature leading to incomplete combustion. Figure 3 indicates variation of the carbon monoxide concentration in the flue gas from different incinerator in different runs. The concentration was highest initially when the temperatures are also lower and decreased with time. High levels of CO indicate that the combustion gases were not held at a high temperature in the presence of oxygen for a long enough time to convert CO to CO_2. The variation depends on the level of temperature during operation of incinerator which determines the extent of combustion of organic matter to CO_2. The trend shows the lower the temperature the higher the release of carbon monoxide. This explain that low combustion result into incomplete combustion, thus result into high release of CO, which also indicated poor performance of the incinerator.

Figure 3 indicates variation of the carbon monoxide concentration in the flue gas from different incinerators sampled in different runs. The concentration was highest initially when the temperatures are also lower and decreased with time. High levels of CO indicate that the combustion gases were not held at a sufficiently high temperature in the presence of oxygen for a long time to convert CO to CO_2. The variation depends on the level of temperature during operation of incinerator, which determines the extent of combustion of organic matter to CO_2. Generation of CO is due to limited air supply and temperature leading to incomplete combustion. The trend shows the lower the temperature the higher the release for carbon monoxide. This explain that low combustion result into incomplete combustion thus result into high release of CO which also indicated poor performance of the incinerators (La Fond et al., 1985; Anamul et al., 2012).

The highest concentration was observed for Muhimbili incinerator (9054 mg/m^3), corresponding to a temperature of 634°C and the lowest was at Temeke Hospital (4653 mg/m^3), corresponding to a temperature of 452°C. The variation might also be factored by the amount of waste per circle and type of waste materials put for incineration. The high pick observed at the end of the run was due to shutdown of secondary chamber for the purpose of saving fuel, which resulted in a drop up of temperature and as a result sharp increase of CO concentration level. Further to that the levels of carbon monoxide (CO) vary widely from one incinerator to the other presumably due to the variations in healthcare waste incinerator operations and waste composition, which affect the degree of combustion.

Profiles of carbon dioxide, CO_2

In this study, CO_2 concentration in the flue gas was determined as a %CO_2 in the stack, that is, carbon dioxide percent by volume, based on a dry basis. Figure 4 shows the variation of CO_2 concentration in different incinerators with time or runs. The CO_2 concentration decreases with time indicating that the charged waste load also goes to completion, with low remaining amount of carbon and monoxide capable of converting to CO_2. Initially, the amount of CO_2 is high for all incinerators, depending on type of waste and percent excess air supplied. More CO_2 was observed for MNH and Temeke that indicates good combustion efficiency for these incinerators, but also could indicate undiluted flue gas for these two incinerators. Muhimbili National Hospital had more run due to huge amount of waste generated per day and also varied characteristics of waste compared to other three hospitals under the study. Results indicated that complete combustion was being attained and continued aeration or supply air led to dilution of the flue gas, as time progresses. Similar trends were observed for all incinerators, indicating similar incinerator operation mode that is batch destruction, since waste is loaded after a batch is runs indicate longer cycle times to

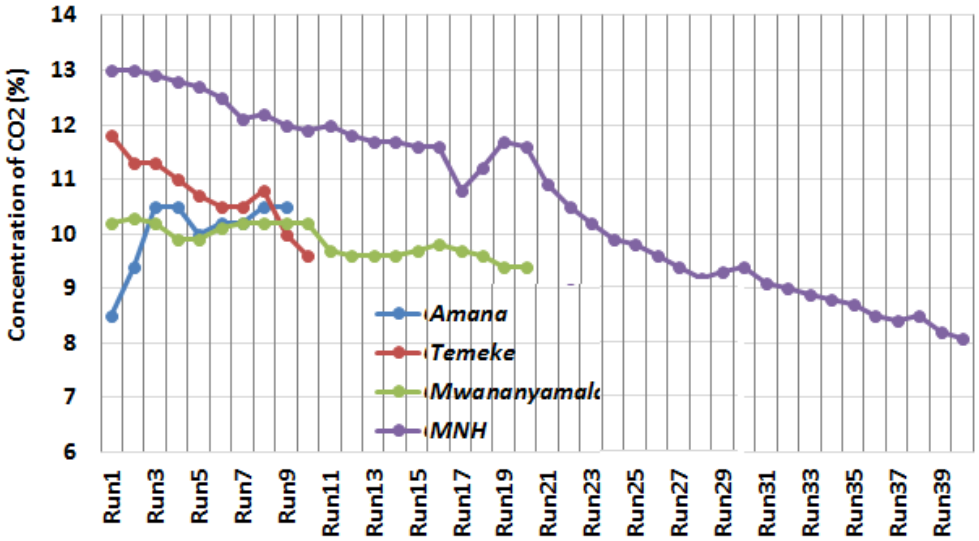

Figure 4. Profiles of the carbon dioxide concentration in the flue gas from different incinerators.

complete the combustion process per batch, such Temeke Hospital incinerator.

CO/CO_2 ratio in the flue gas

Carbon monoxide (CO) is a poisonous, colourless, odourless gas produced by the incorrect or incomplete combustion of healthcare waste, while carbon dioxide (CO_2), although a problematic greenhouse gas, is not toxic to the same degree and is a product of correct or complete combustion. When the CO produced by incineration in parts per million (ppm or mg/m^3) is divided by the CO_2 produced also in ppm we get the CO/CO_2 ratio. Dividing CO by CO_2 effectively cancels the effect of flue gas dilution by air blower and gives a value proportional to the true amount of CO being produced. CO/CO_2 ratio gives a more reliable picture of combustion process than CO (ppm) alone.

Figure 5 shows the variation of the CO/CO_2 ratio with residence time during healthcare waste incineration for the four incinerators studied. The data from Temeke Hospital shows that the ratio falls immediately to minimum after the combustion process is started with the values being lowest compared to other incinerators. At MNH, on the other hand, the CO/CO_2 ratio starts at a highest value, and decreases continuously to zero. While the data from MNH and Temeke shows higher initial values followed by faster decrease in CO/CO_2 ratio with time, the ratio remained constant and lowest for Amana and Mwananyamala Regional Hospital incinerators. This shows that the secondary chambers of the incinerators at MNH and Temeke have good performance in terms of raising temperature and providing enough residence time in order to burn the CO to CO_2 as incineration cycle time proceeds. On the other hand, the situation observed at Amana and Mwananyamala Regional Hospitals can be attributed to low amount of waste feed and excess air supply (Table 1), since combustion efficiency was observed to be lower for these two incinerators.

Although CO/CO_2 testing has not been widely utilized in the waste combustion sector, it may provide a quick and effective additional method of ensuring the performance of healthcare waste incinerators (La Fond et al., 2012). In Figure 6, the values of the CO/CO_2 ratio were initially highest (for Temeke and MNH), which decreased from 0.065 and 0.032 to about 0.001, in about 20 and 9 runs for MNH and Temeke incinerators, respectively, which is about two orders of magnitude change in the ratio. The ratio of CO/CO_2 reflects the completeness of waste combustion and its decrease is accompanied by a decrease in the heat generated by waste combustion, indicating that the incinerators at MNH and Temeke are loaded with larger quantities of waste which is destroyed faster.

The lower values of the ratio CO/CO_2 can be described by the fact that the heat of reaction for the formation of CO_2 is a factor of 3.5 higher than for CO. Thus, formation of CO instead of CO_2 will be favoured by the combustion process. But instead, results showed that CO_2 formation is favoured despite the energy barrier. The fact that CO/CO_2 ratio is lower than 0.1, shows that the combustion processes in the incinerators were efficient leading to higher generation rate of CO_2 compared to CO as the incineration cycle proceeds. The terms excess air and excess oxygen are commonly and synonymously used to define combustion. The percentage of excess air is the amount of air above the stoichiometric requirement

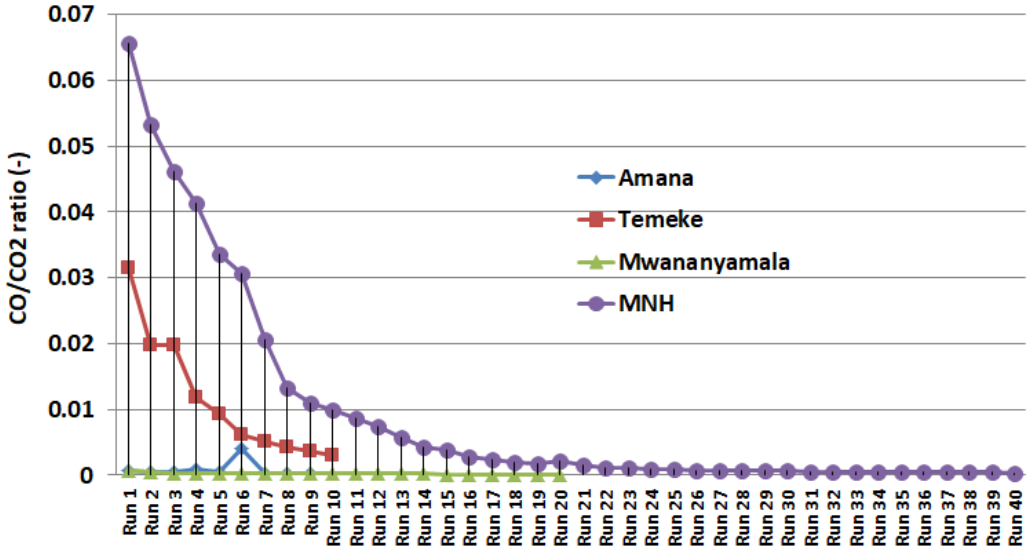

Figure 5. Variation of the CO/CO_2 ratio with time during healthcare waste incineration for the four incinerators studied.

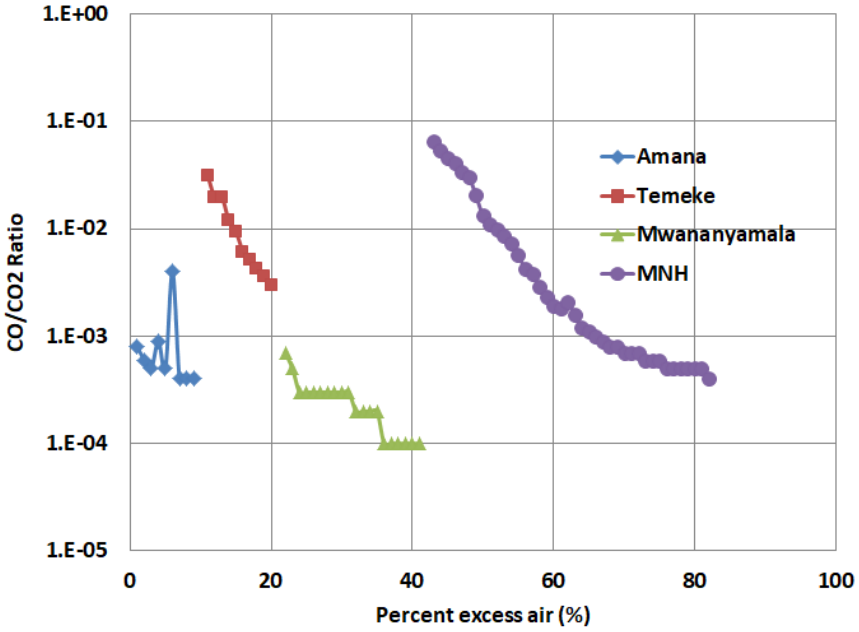

Figure 6. Effect of increasing percent excess air on CO/CO_2 ratio during healthcare waste incineration.

for complete combustion. To avoid products of incomplete combustion (PICs), especially carbon monoxide (CO), excess air is usually added.

Variation of NOx concentration with incineration time

Among the major environmental concerns related to incineration are the emissions of nitrogen oxides (NO_x), which have been shown to strongly contribute to the formation of acid rain and photochemical smog. During the incineration of municipal solid waste in grid furnace incinerators for instance, NO is the major component of the NO_x formed, representing 95% of those emissions (Abbas et al., 1997). In those conditions, past research

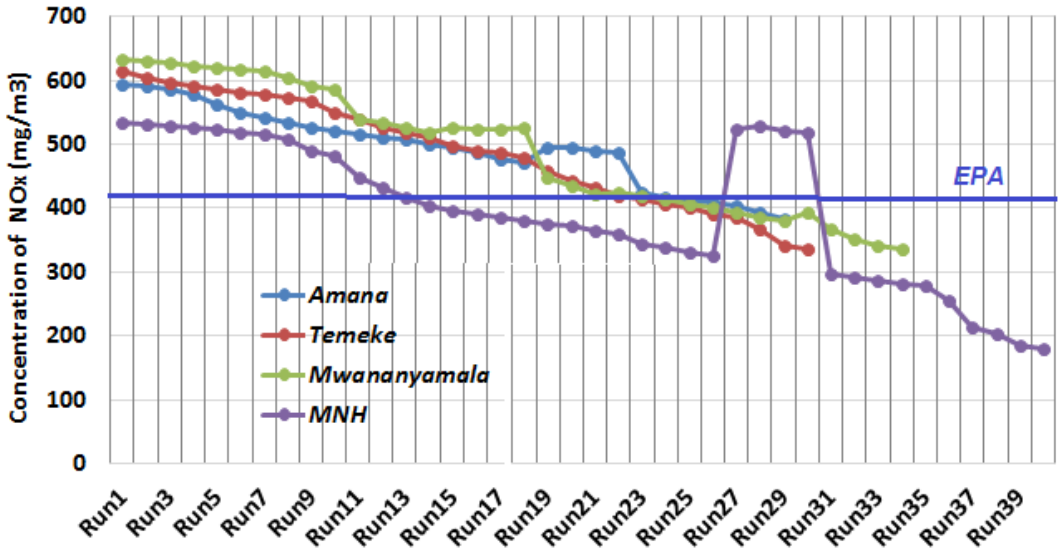

Figure 7. Profiles of the NO_x concentration in the flue gas from different incinerators.

(Sorum et al., 2001) showed that more than 95% of the NO is formed from the fuel-NO mechanism. Moreover, past studies have demonstrated that no NO_2 and N_2O are emitted during similar tests, so that the only NO_x is NO (Rogaume et al., 2002). Therefore, it is justifiable to concentrate only on the establishment of the main variables controlling NO. Also, past studies have shown that NO is generated from three sources: thermal NO, prompt NO and fuel NO (Miller and Bowman, 1989; Rogaume et al., 2002).

In the incineration of healthcare waste, nitrogen oxides NO_x (NO, NO_2) arise, which are formed essentially from the nitrogen contained in the waste, from the combustion process itself and from spontaneous reaction (so-called prompt NO_x). As a rule, nitrogen oxide concentrations in the flue gas were measured continuously at these plants. To avoid damage of the KANE9000 probe, NO_x measurement we conducted by sampling the gas at short intervals of time, covering the whole incineration cycle time. Figure 7 shows the levels of NO_x concentration in the four incinerators with time during test runs, compared to the EPA standard. Initially, all incinerators emitted higher levels of NO_x, which decreased with time, until the concentration level was below acceptable the limit (411 mg/m^3). This can be attributed to the decrease in materials in the healthcare waste leading to NO_x formation as combustion proceeds in a batch operated incinerator (Wang, 2002).

Thus, types of measures have been recommended in order to reduce NO emissions, the optimization of combustion parameters and the introduction of secondary reduction techniques or flue gas treatment using APCDs. Since the cost imposed by secondary reduction techniques is high, optimization of the combustion process is therefore the preferred approach.

Profiles of SO_2 emissions in different incinerators during burning process

Figure 8 shows the variation of SO_2 concentration with time for the four incinerators studied, which were also compared to the EPA standard ⟨set at 88.1 mg/m^3⟩. In all cases the SO_2 concentration decreased with time to the maximum allowable level. Figure 8 indicates that sulfur dioxide is released from incinerators during incineration of healthcare waste. The concentration levels varied between the studied incinerators. The highest level (2208 mg/m^3) was observed to MNH incinerator, while the lowest values were observed at Mwananyamala hospital incinerator.

At some point between run new load of waste is added and depending on the constituent of the waste materials (some are too wet) usually there is a fall of temperature but still there is increase of SO_2 due to new load of waste materials.

Effect of temperature on pollutant concentration in the flue gas

Effect of temperature on CO_2 concentration in the flue gas

Results showed further that maintaining high temperature increases the release of CO_2, as depicted in Figure 9, which shows the variation of CO_2 concentration with temperature for the four incinerators studies. The CO_2

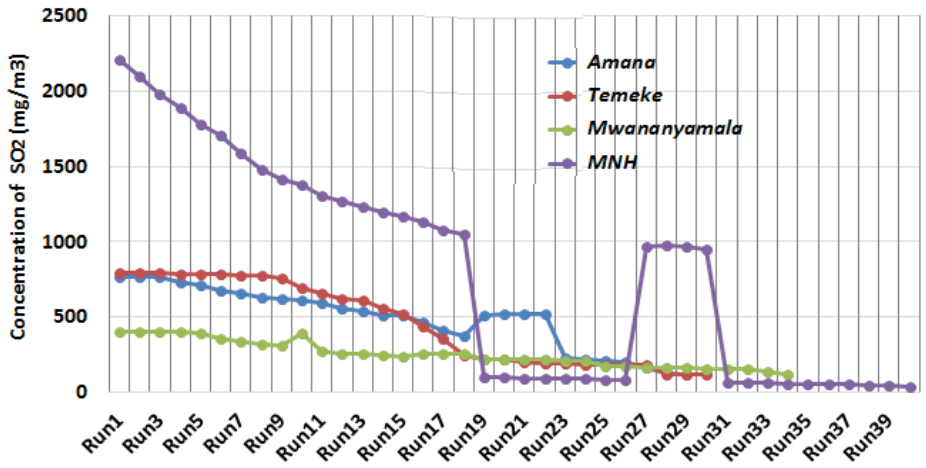

Figure 8. Profiles of the sulfur dioxide concentration in the flue gas from different incinerator.

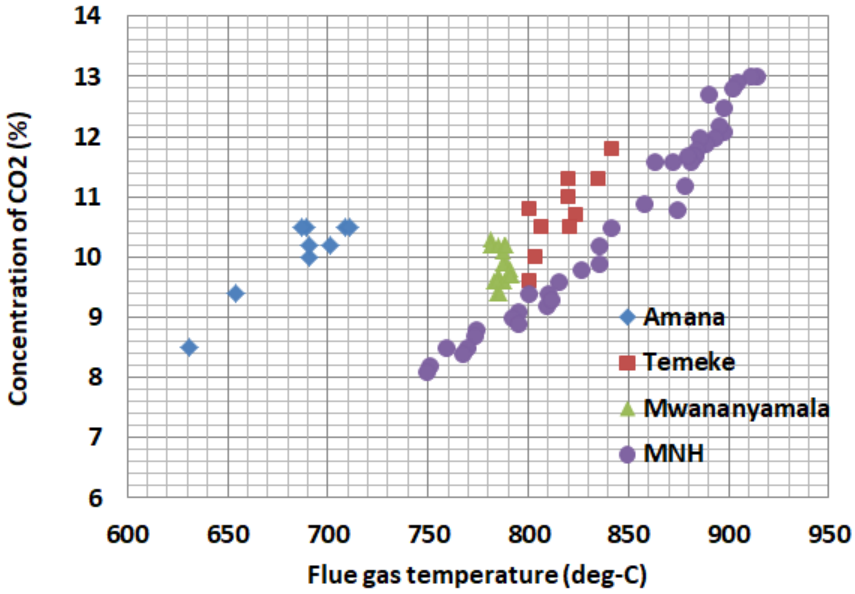

Figure 9. Effect of flue temperature on flue gas (CO_2) concentration.

concentration increased with temperature for all incinerators, which agrees with the fact that at higher temperature, organic matter and CO are converted completely to CO_2 in presence of oxygen (La Fond et al., 2012). The results showed similar correlation of CO_2 concentration with temperature for all studied incinerators, indicating that temperature is one of the key factors, which determine the time variation of CO_2 during operation of incinerators. The highest and lowest releases were observed at MNH incinerator, that is, 13 and 8%, respectively. The lowest CO_2 concentration at MNH corresponds to the low temperature about 750°C, which indicates further that the data was taken at the beginning of the cycle when the incinerator was fully loaded with the waste, while the highest CO_2% corresponds to the final incineration data where the temperature is also high as shown in Figure 1.

Figure 9 shows also the incineration temperature ranges for each incinerator as a span of data on the horizontal axis, which is widest for MNH, from 740 to 920°C as compared to Amana Hospital incinerator from 630 to 710°C only, which is shifted towards the left in Figure 5. The Mwananyamala incinerator, however was operated in a very narrow temperature range of 780 to

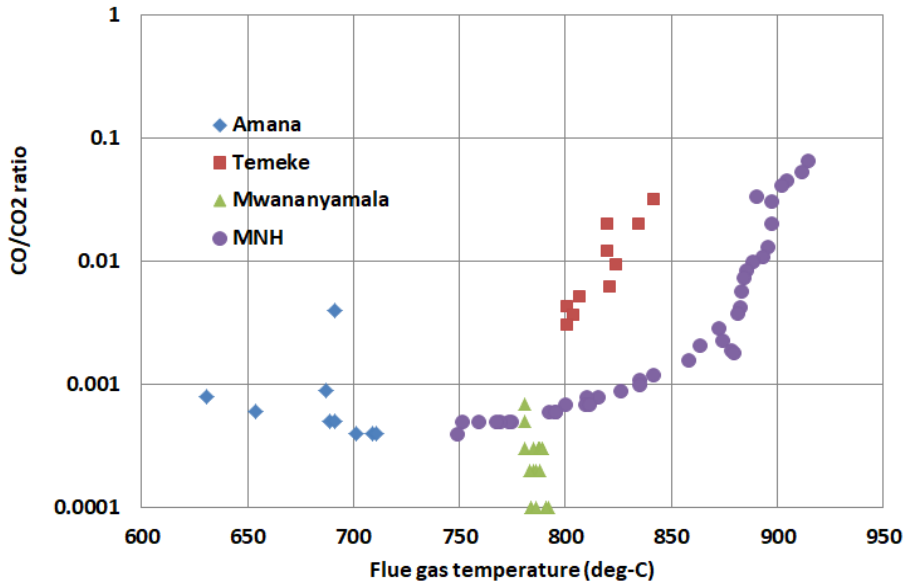

Figure 10. Variation of CO/CO_2 ratio with temperature in the studied incinerators.

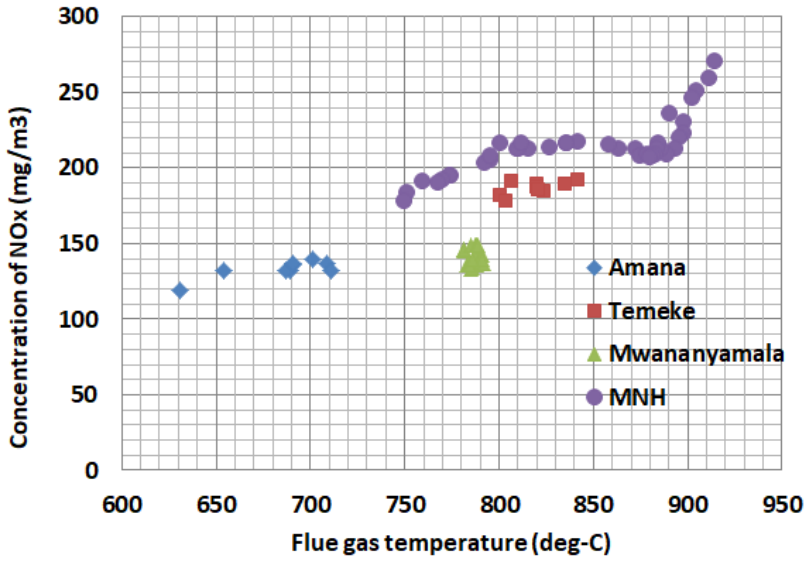

Figure 11. Effect of flue temperature on flue gas NO_x concentration.

790°C only.

Effect of temperature on CO/CO2 ratio in the flue gas

Figure 10 shows the relationship between temperature and the CO/CO_2 ratio for the four incinerators studied. The CO/CO_2 ratio was observed to increase with flue gas temperature for MNH and Temeke incinerators. The CO/CO_2 ratio produced by the carbon-oxygen reaction is assumed or inferred from the waste particle temperature during combustion, which is also a measure of the flue gas temperature, and secondary chamber temperature.

Effect of temperature on NOx ratio in the flue gas

Figure 11 shows the variation of NO_x concentration with temperature in the four different incinerators studied. The NO_x concentration was observed to be temperature dependent such that at low temperature, NO_x levels did not increase strongly with temperature. The highest NO_x

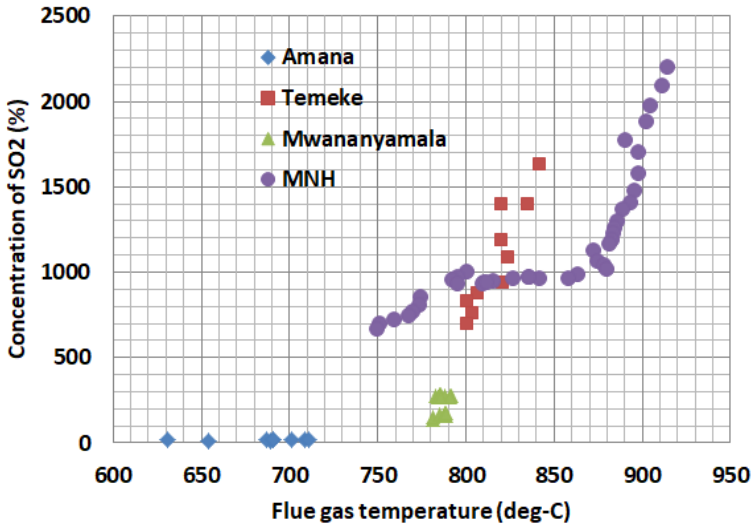

Figure 12. Effect of flue temperature on SO_2 concentration in the flue gas.

level (270 mg/m^3) concentration was observed at MNH at a higher temperature of 910°C and the lowest level (120 mg/m^3) was recorded at Amana hospitals corresponding to a low temperature of 634°C. Thus, high temperature slightly increases the NOx concentration in the flue gas. The NOx levels in the flue gas depend also on the nitrogen content or in organic compounds in the healthcare waste and also nitrogen from the air can be converted to NOx when conditions are favorable, including high temperature (Allen et al., 1986; Tezanou et al., 2009).

Effect of temperature on SO_2 concentration in the flue gas

Figure 12 shows the variation of SO_2 concentration in the flue gas with temperature for the two incinerators studies. Results for (MNH and Temeke) incinerators showed stronger dependency of SO_2 emissions on temperature. Result from both incinerators revealed that SO_2 concentration increases with temperature, indicating high combustion efficiency of the incinerators in destroying sulfur containing compounds at higher temperature. With elevated temperatures, the levels of SO_2 increased dramatically. This necessitates application of air APCDs which can trap SO_2, such as fixed-bed or wet-scrubbers. Again, despite other factors temperature is a key factor to the variation of SO_2 level in the flue gas during incineration of healthcare waste a case depicted strongly for MNH and Temeke hospital incinerators. As reaction time increases, the concentration of SO_2 showed a decreasing trend. This may be due to the amount of sulfur in organic solid waste diminishing as incineration cycle proceeds towards the end. Influence on the production of SO_2. Higher temperature leads to sufficient gasification reaction, that is, high conversion of sulfur in the waste to SO_2. Some inorganic sulfur and sulfur chain may produce more SO, which reacts further with oxygen to yield SO_2.

Effect of percent excess air on combustion efficiency and pollutant concentration in the flue gas

In order to have the most efficient combustion during incineration process, the quantity of fuel and air would be in a perfect ratio to provide perfect combustion with no unused fuel or air, that is, theoretical perfect combustion or stoichiometric combustion. In practice, however, for safety and maintenance needs, additional air beyond the theoretical amount needs to be added to the combustion process, referred to as “excess air” (Abbas et al., 1997). With incineration, if some excess air is not added to the combustion process, unburned fuel, soot, smoke, and carbon monoxide exhaust will create additional emissions and fouling of chambers and chimney surfaces. Although, excess air is needed from a practical standpoint, too much excess air can lower combustion efficiency during incineration, so that a balance must be found between providing the optimal amount of excess air to achieve ideal combustion and prevent combustion problems associated with too little excess air (such as higher emissions concentration), while not providing too much excess air to reduce combustion efficiency (CE) (Rogaume et al., 2002).

Significant amounts of energy can be lost because of too much air entering the incinerator, resulting in heat loss through flue gases and cooling of chambers. The excess air results in oxygen that is not consumed during

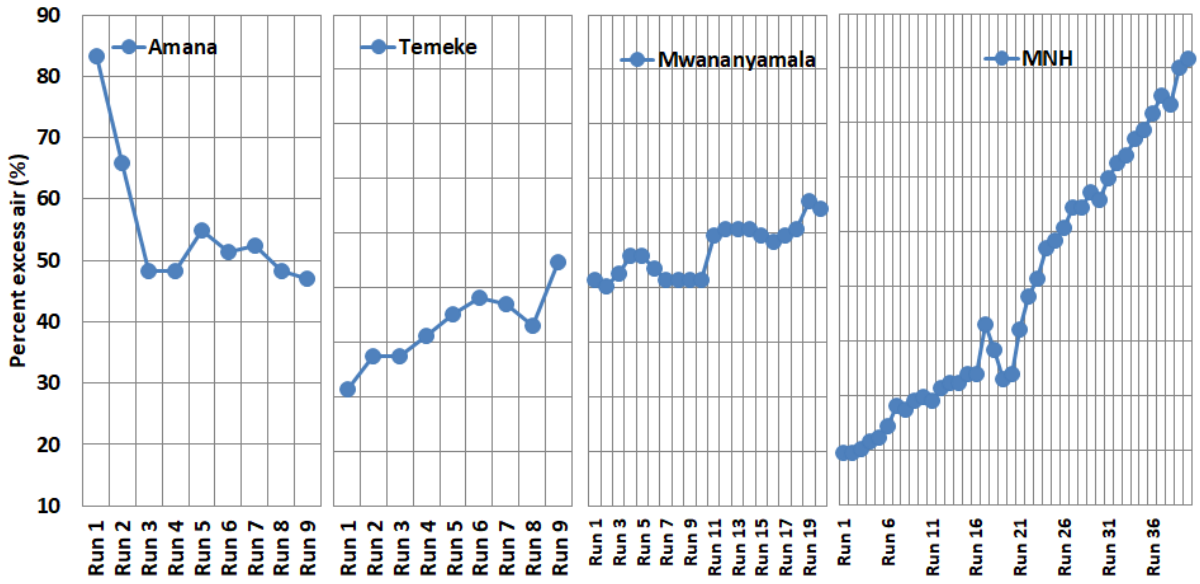

Figure 13. Range of values of percent excess air observed in the four incinerators during test runs.

combustion, and this oxygen and the accompanying nitrogen absorbs otherwise usable heat and carries it out of the stack. However, this ideal (known as the stoichiometric air-to-fuel ratio) is difficult to reach because health waste and air don't completely mix, meaning that a certain amount of excess air will always be necessary for complete combustion. Another challenge leading to uncertainty in supplying excess air is the composition variation in the healthcare waste.

Figure 13 shows the series of values of percent excess air observed during incineration test runs from four incinerators studied. While the results from Amana regional hospital showed a decrease in percent excess as incineration proceeded, the observation from other sites shows increase in percent excess. This can be attributed to poor aeration via burner or blower caused by blockage of air supply pipes due to arches. On the other hand, Temeke, and Mwananyamala hospital incinerators showed slight increase in percent excess air with time, due to constant aeration, while the waste load diminishes in the primary chamber, and also the flow of pyrolytic gases into the secondary chamber decreases with time. Data from MNH showed a faster increase in percent excess attributable to both high CE and temperature, as well as, blower capacity, and portioning of secondary chamber (that is, at the top of the primary chamber).

Figure 14 shows the variation of CE with percent excess air for the four incinerators studies. There is a clear observation that the four incinerators were operated at different percent excess ranges, starting with a low range at Amana, Temeke, Mwananyamala and a highest range at MNH.

In general, most incinerators indicated that initially set air flow rate from a blower becomes highly excess towards the end of the incineration cycle, when the fired load becomes smaller as shown in Figure 14. Thus, increasing excess air requirements as the firing rate of the incinerator decreases (towards the end of the cycle) leads to lower efficiency at the end of the cycle. Initially, the CE was high for Amana and MNH, which dropped later as percent excess, was increasing. The values of percent excess air corresponding to the maximum values of CE are shown also as an insert to Figure 14.

Figure 15 shows the variation of emissions concentration (CO, CO_2 SO_2, and NO_x) in the flue gas with percent excess air for the four incinerators studies. In general, the concentration of these gases in the flue gas decreased with percent excess air. The data from MNH forms a base case, where by the percent excess air varied from 20 to 91.7%, while other incinerators were operated using percent excess within this range. The decrease in concentration with percent excess air can be attributed to dilution of the flue gas rather than improved combustion, since this contradicts the trend for CO_2 which should increase at higher percent excess if the improved combustion was the controlling factor. Moreover, SO_2 concentration should also increase if improved combustion was the controlling factor, but it decreased with percent excess air similar to NO_2, and CO. The fact that CO concentration decreased with percent excess is linked to both improved combustion and dilution of the flue gas.

Rogaume et al. (2009) studied the effect of increasing percent excess air on NO_x formation (as NO) and observed that NO emissions in a fixed bed combustor for municipal solid waste increased with percent excess air,

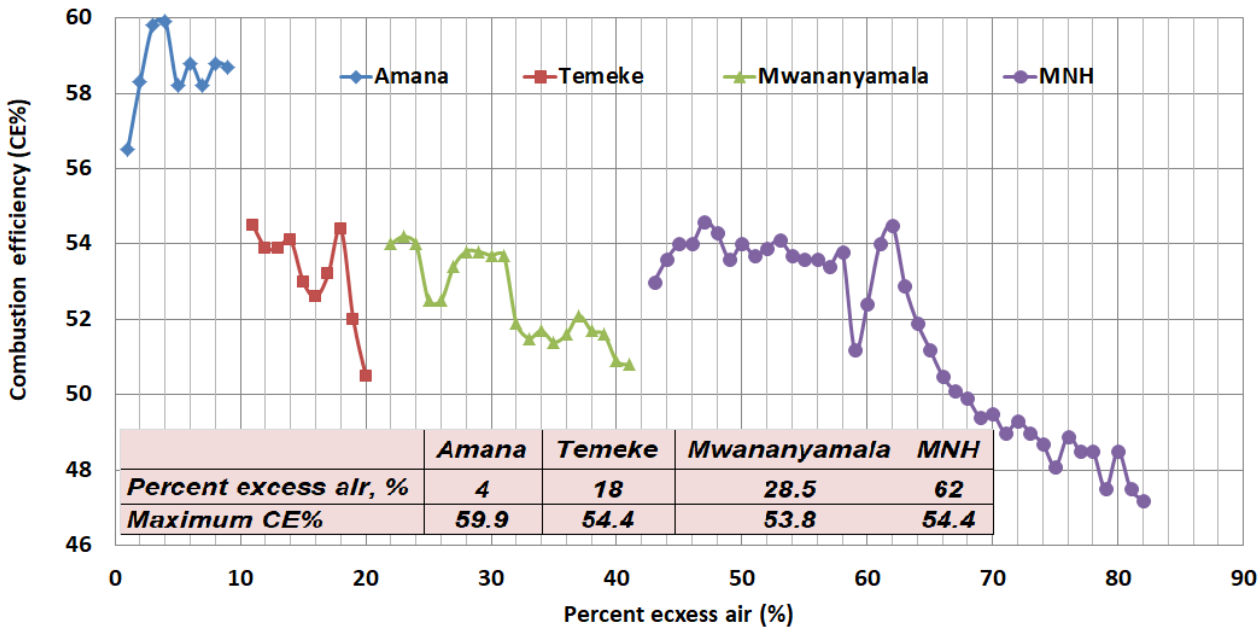

Figure 14. Effect of increasing percent excess air on combustion efficiency during incineration.

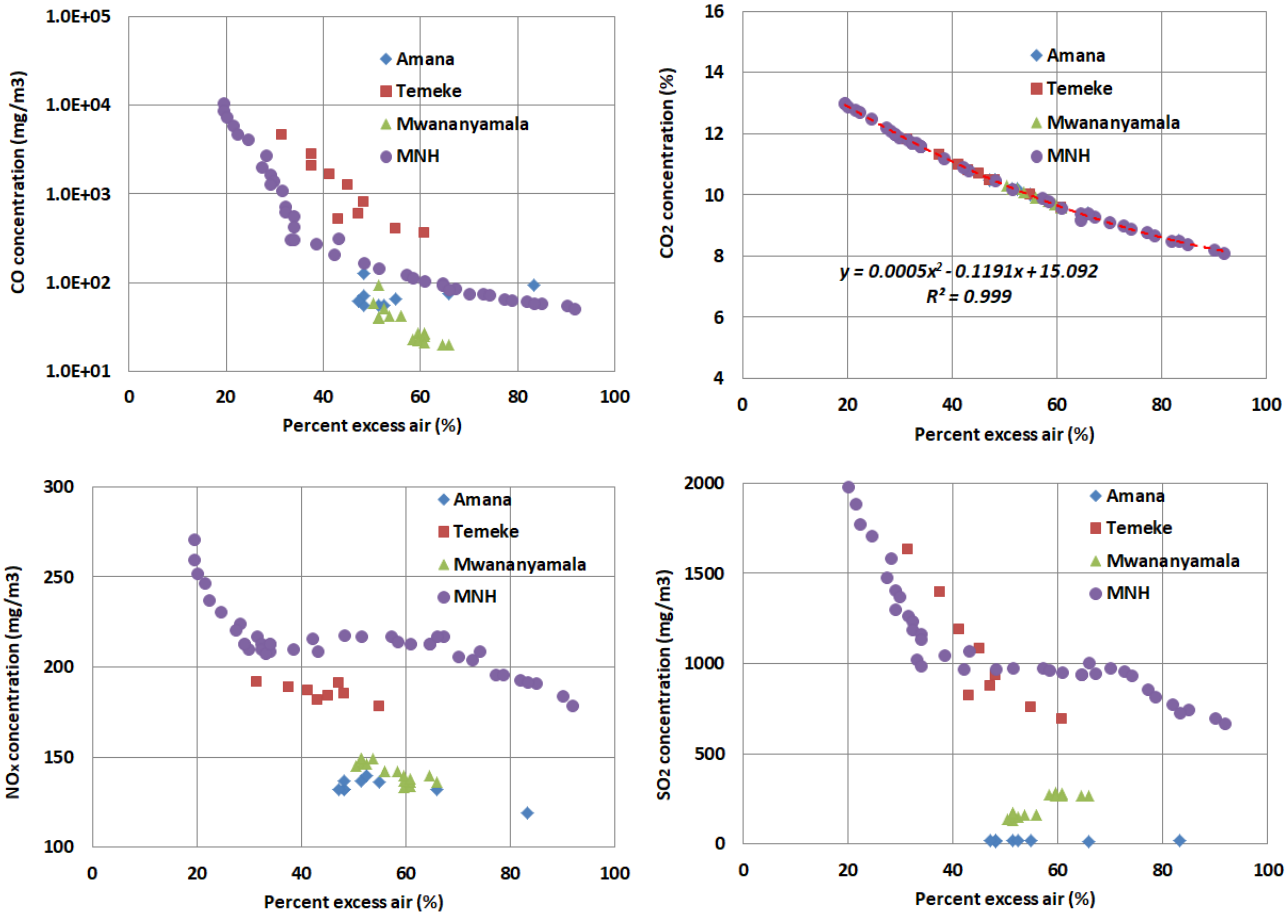

Figure 15. Effect of percent excess air on emissions concentration in the flue gas.

different from results shown in Figure 15 (from fixed grate double chamber incinerators for healthcare waste). The NO emissions were, however, measured in mg/g of waste incinerated, while data in Figure 15 is presented based on mg/m^3 of flue gas, which is subject to dilution challenges at higher excess air supply.

DISCUSSION

Waste are produced everywhere in the world and tones of healthcare waste production are no exception. Healthcare waste can be infectious, contain toxic chemicals and pose contamination risks to both people and the environment. If patients are to receive healthcare and recover in safe surroundings, healthcare waste must be disposed of safely. One of the healthcare waste treatments methods used worldwide is healthcare waste incineration.

During incineration process different pollutants from healthcare waste are dispersed into air, which may have adverse health effects associated with mass burn incineration are of great concern as large population groups and workers may be exposed to derived toxic substances. These effects can be exposed directly through inhalation or indirectly through consumption of food or water contaminated by deposition of the pollutants from air to soil, vegetation, and water.

Apart from toxic heavy metals, which may be present, there are different oxides of non-metals the NO_x and SO_2 emissions will contribute, respectively, for the formation of acidic aerosols. It should be noted that SO_x and NO_x emissions as a result of incineration of waste is can be minimize by flue gas treatment like scrubbing medical waste cannot be a good comporting candidate due to pathogens content, elimination of which leads to SO_2 and NO_x. The nitrogen and sulphur dioxide, which are associated to respiratory short-term effects especially to individuals with a particular susceptibility should be removed from the gas. Carbon monoxide emissions result when carbon in the waste is not completely oxidized to carbon dioxide (CO_2). High levels of CO normally indicate that the combustion gases were not held at a sufficiently high temperature and long enough residence time. In the presence of oxygen (O_2) for a long enough time converts CO to CO_2, or that quenching has occurred.

It is hereby recommended to set country standards for the emission, which requires use of various air pollution control devices as well as monitoring and inspection and permitting programs. To meet the required standard effective waste reduction and waste segregation should be promoted ensuring that only the smallest quantity of appropriate waste types is incinerated. Future studies on the levels of dioxin and furan emissions from these incinerators is required as these deadly compounds may resulted into public health risks due to persistent and bio-accumulative nature of these compounds.

Conclusions

(1) In all incineration cycles the temperature of the flue gas increased with time, as recorded in time intervals to the end of the batch or cycle.
(2) CO, SO_2, and NO_x levels were initially above the recommended EPA-standard for all incinerators, except at the end of cycles.
(3) CO_2 levels were higher in the flue gas, but decreased with the time attributable to completion of organic matter in the primary/secondary chambers.
(4) The NO_x, SO_2 and CO_2 increased slightly with temperature, indicating high combustion efficiency at high temperature.
(5) Higher levels of NO_x, SO_2 and CO necessitate use of APCDs for the gas treatment.

The study has indicated that majority of incinerators operate, while emitting pollutants above recommended standards by EPA, which decreases to allowable levels within a cycle time. A concern on the danger of toxin gas emission, e.g., SO_2 and NO_x from incinerators can be minimized by use of APCDs. Emissions may be controlled by modification of process techniques and physical parameters to optimize combustion conditions, or by employment of abatement techniques. The level of abatement at an incinerator plant varies, depending on the size of the plant, age and emission regulations. In order to address the problem of toxic gas emission, authorities must set new standards for incinerators and recommend for a better environmental friendly technologies for the management of healthcare waste.

Recommendations

(1) Incinerators should be located away from health facility vicinity and residential areas and in a reward direction to avoid direct exposure to emission from incinerators.
(2) Scaling up program for improving HCWM in Tanzania should be supported with consideration of promoting other alternative methods of waste management, especially in urban area where space for sitting up incinerator is a problem.
(3) Regular monitoring and maintenance of the incinerators should be done to rectify structural defects, which result in emission of unacceptable levels of smoke, which is likely to affect first the health of the incinerator operators and the entire community.
(4) Further investigations on other toxic organic pollutants, such as dioxins and furans are recommended in the future.

ACKNOWLEDGEMENT

The completion of this study has been the results of assistance received from all management teams of the hospitals involved in the study (Temeke, Mwananyamala and Ilala Regional hospitals, and MNH).

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

REFERENCES

Abbas T, Costen P, Lockwood FC (1997). A review of current NO_x control methodologies for municipal solid waste combustion process. 4th European Conference on Industrial Furnaces and Boilers, London.

Allen RJ, Brenniman GR, Darling C (1986). Air Pollution Emissions from the Incineration of Hospital Waste. Journal of the Air Pollution Control Association 36(7):829-831.

Allsopp M, Costner P, Johnston P (2001). Incineration and Human Health: State of Knowledge of the Impact of Waste Incinerators on Human Health - Executive Summary. Environmental Science and Pollution Research 8:141-145.

Anamul H, Tanvir M, Rahman J (2012). Zinc and Nickel of bottom ash as a potential diffuse pollutant and their application as fine aggregate. Journal of Civil Engineering Research 2(6):64-72.

Ardevol E, Minguilon C, Garcia G, Serra ME, Gonzalez CA, Alvarez L, Elitja R, Lafuente A (1999). Environmental tobacco smoke interference in the assessment of the health Impact of a municipal waste incinerator on children through urinary thioether assay. Public Health 113:295-298.

Baharun S, Robiah A, Khairili M, Arshad A, Tahir A, Rashid M, Zamri I (2005). Variables affecting the combustion efficiency of a clinical waste incineration process. Jurnal Teknologi 42(F):11-24.

Batterman S (2004). Findings on assessment of small-scale incinerators for healthcare waste, World Health Organization, Geneva pp.1-65.

Demirezen D, Aksoy A (2006).Heavy metal levels in vegetables in Turkey are within safe limits for Cu, Zn, Ni and exceeded for Cd and Pb. Journal of Food Quality 29:252-265.

Enviros Consulting Ltd (2004) Review of environmental and health effects of waste management: Municipal solid waste and similar wastes. London: Department for Environment, Food and Rural Affairs (19) (PDF) environmental and health risks related to waste incineration. Available from: https://www.researchgate.net/publication/334563514_Environmental_and_health_risks_related_to_waste_incineration [accessed Aug 03 2020].

Ernesto T, Savino A (2019). Environmental and health risks related to waste incineration, Waste Management and Research 37(10):0734242X1985970.

Ferronato N, Torretta V (2019). Waste mismanagement in developing countries: A review of global issues. International Journal of Environmental Research and Public Health 16(6):1060:1-28.

Gitonga LK (2017), Factors influencing waste segregation among staff in Chuka level four hospital. Rehabilitation Science 2(4):91.

Goren A, Hellmann S, Gabbay Y, Brenner S (1999). Respiratory problems associated with exposure to airborne particles in the community. Archives of Environmental Health: An International Journal 54(3):165-171.

Hettiarachchi H, Meegoda JN, Ryu S (2018). Organic waste buyback as a viable method to enhance sustainable municipal solid waste management in developing countries. International Journal of Environmental Research and Public Health 15:2483.

International Committee of the Red Cross (ICRC) (2011). International Committee of the Red Cross, Healthcare Waste Management, Geneva, Switzerland.

La Fond RK, Kramlich JC, Randall S, Gary SS (1985) Evaluation of continuous performance monitoring techniques for hazardous waste incinerators. Journal of the Air Pollution Control Association, 35(6):658-663.

La Fond RK, Kramlich JC, Randall S, Samuelsen GS (2012). Evaluation of continuous performance monitoring techniques for hazardous waste incinerators. Journal of the Air Pollution Control Association 35(6):658-663.

Manyele S, Kagonji IS, Mrisho J (2011). Assessment of healthcare waste incinerator performance based on physical characteristics of ashes. Engineering 3(10):1045-1053.

Manyele SV, Anicetus H (2006). Management of healthcare waste in Tanzanian hospitals. Tanzania Health Research Bulletin 8(3):177-182.

Manyele SV, Mujuni CM (2010). Current status of sharps waste management in lower level health facilities in Tanzania. Tanzania Health Research Journal 12(4):257-264.

Matee V, Manyele SV (2015a). Performance of a large-scale medical waste incinerator in a referral hospital. Engineering 7: 676-690.

Matee V, Manyele SV (2015b). Analysis of temperature profiles and cycle time in a large-scale medical waste incinerator. Engineering 7:717-732.

Miller JA, Bowman CT (1989). Mechanism and modeling of nitrogen chemistry in combustion. Progress Energy Combustion Science 15:287-338.

Oppelt ET (1987).Incineration of hazardous waste: A critical review. Journal of Air and Waste Management 37(5):558-586.

Parry J Stevens A (2001). Prospective health impact assessment: pitfalls, problems, and possible ways forward. British Medical Journal 323:177-1182.

Pluss A, Pirkle JL, Kaufman RB, Brody DJ, Hickman T, Ferrell R (1991).Characterization of lead and other heavy metals in fly Ash from municipal waste incinerators. Hazardous Waste and Hazardous Waste Materials 8(4):275-292.

Rogaume T, Auzanneau M, Jabouille F, Goudeau JC, Torero JL (2002). The effects of different airflows on the formation of pollutants during waste incineration. Fuel 81:2277-2288.

Singh S, Prakash, V (2007). Toxic environmental releases from medical waste incineration: A review. Environmental Monitoring and Assessment 132(1-3):67-81.

Sorum L, Skreiberg O, Glarborg P, Jensen A, Dam Johansen K (2001). Formation of NO from combustion of volatiles from municipal solid wastes. Combustion and Flame 124(1-2):195-212.

Takata T (2003). Survey on the health effects of chronic exposure to dioxins and Its accumulation on workers of a municipal solid waste incinerator, rural part of Osaka prefecture, and the results of extended survey afterwards. Industrial Health 41(3):189-96.

Tezanou J, Rogaume T, Richard F, Andzi Barhé T, Jabouille F (2009). Influence of waste composition on NOx emissions from incinerators. International Journal of Heat and Technology 27:1-8.

Wajs J, Bochniak R, Golabek A (2019). Proposal of a mobile healthcare waste incinerator with application of automatic waste feeder and heat recovery system as a novelty in Poland. Sustainability11:4980-4998.

Wang Y (2002). A combustion test facility for testing low NOx combustion systems', ASME Turbo Expo 2002: Power for land, sea, and air, Amsterdam, The Netherlands.

World Health Organization (WHO) (2011). Healthcare and its safe management, World Health Organization, Geneva, Switzerland.

World Health Organization (WHO) (2014), Safe management of wastes from healthcare activities, Geneva: World Health Organization World Health Organization, Geneva, Switzerland.

World Health Organization (WHO) (2018). Healthcare Waste. World Health Organization Geneva, Switzerland.

Wiedinmyer C, Yokelson RJ, Gullett BK (2014). Global emissions of trace gases, particulate matter, and hazardous air pollutants from open burning of domestic waste. Environmental Science and Technology 48:9523-9530.

Wiles C, Shepherd P (1999). Beneficial use and recycling of municipal waste combustion residues. A comprehensive resource document national renewable energy laboratory, USA.

World Bank (1999). Technical guidance on municipal solid waste incineration. The International Bank for Reconstruction and Development the World Bank.