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Medical Waste Management and Design of a Low-Cost Incinerator for Reduction of Environmental Pollution in a Multi-System Hospital

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ABSTRACT

Pollution of the environment and inappropriate management of medical wastes are major challenges facing developing countries and this must be tackled with recent technology for public health, enhanced natural ecosystems, and a better environment. This research is a two-step process that involves the assessment of the existing Hospital waste management practices in a multi-system Hospital in Ado-Ekiti, Nigeria. Excess air, kerosene (auxiliary fuel), single chamber, Batch-fed (Manual feeding), and controlled air incinerator were designed. Wastes were loaded once at the beginning of the combustion cycle followed by combustion, ash burnout, cool down, and ash removal to assist medical waste management. Findings revealed that personnel involved in handling medical waste were equipped with inadequate protective gear. Medical waste was handled together with municipal waste and both wastes were incinerated in an open dumpsite without engineered sanitary landfill at disposal locations constituting a nuisance with a high risk of pollution to the surrounding environment. The incinerator was designed for a waste load of 269 $kg.day^{-1}$. It consists of four zones; the waste and combustion zone (2.7 m × 1.8 m × 1 m), the ash zone (0.23 m height), the combustion fumes and one-second retention zone (0.43 m height) as well as the excess air zone (0.46 m height). This low-cost medical waste incinerator has a lot of improvement, operational effectiveness, and efficiency to the currently available techniques. Viable recommendations made will improve the state of environmental health and reduce the harmful effects of medical waste.

INTRODUCTION

In developing countries such as Nigeria, waste incineration is the primary method for managing hospital waste, with the economic advantages of destroying pathogens in the waste stream and reducing waste volume and reactivity. However, if handled improperly, incineration has a significant impact on the environment, releasing pollutants in the form of gaseous emissions and ash, which have environmental and public health implications (Adama et al. 2016). HWM has been regarded as minimal in studies undertaken in impoverished nations, with generators and handlers lacking in general awareness of relevant issues (Manyele et al. 2003). Although healthcare waste is classified as hazardous because it constitutes a serious direct threat to human health (WHO 1999), inadequate HWM is still prevalent in developing nations such as South Africa, Nigeria, Swaziland, Mozambique, Kenya, and Tanzania (Manyele 2004).

Past Studies

Hospital waste generation varies not just between nations, but also within countries, depending on infrastructure, management system, percentage of reusable items, and percentage of waste generated on an outpatient basis (WHO 2002). In developing countries like Nigeria, undeveloped open lands are often converted into waste disposal sites, even within planned residential areas; indiscriminate dumping of waste causes environmental and health hazards. Despite the controlled burning that is supposed to occur when using an incinerator, air pollution still occurs (Akpe et al. 2016). This is primarily due to insufficient design and the absence of air pollution control devices, which is a feature of most incinerators used in Nigeria for managing hospital waste. People migrated in substantial numbers to developed cities as a result of rapid industrial development, job opportunities, and urbanization (Lin et al. 2022, Patel & Burkle 2012, Muthukannan et al. 2019). Huff & Angeles (2011) and Cassidy et al. (2014) found that migration and industrial development had a negative influence on the environment, particularly on water, air, and soil. All kinds of life on Earth depend on clean air and water, and polluting any or both will be a severe problem. Human activities affect the regional ecological environment, climate, hydrology, vegetation, biogeochemical cycles, and biodiversity on a variety of temporal and spatial dimensions, all of which contribute to environmental pollution (Collier et al. 2013).

The rapid rise of hospitals in both the commercial and public sectors has helped to rebuild the community's health (Agunwamba et al. 2013). Although not all hospital wastes are susceptible to disease transmission, biomedical waste makes up about 1-2 percent of the entire municipal solid waste (MSW) stream. 80-85% of hospital trash is non-infectious, 10% is contagious, and 5% is harmful (Gupta & Boojh 2006). Although hospitals' primary goal is to restore human health, hospital waste disposal is a major concern. Bio-medical waste has recently become a major source of worry for environmental law enforcement agencies, the media, and the general public, not only in hospitals and nursing homes (Ramesh et al. 2008). Bio-medical waste is generated in a variety of settings, including hospitals, laboratories, clinics, nursing homes, and medical, dental, and veterinary clinics. Some of these wastes pose major health and environmental dangers to people (Ramesh et al. 2008). Biomedical waste management has recently become a serious concern for hospitals, nursing homes, and the environment. The consequences of improper biomedical waste management have sparked global alarm, especially given its far-reaching implications (Mathur et al. 2012, Vasistha et al. 2018).

Medical waste has continued to pique public interest due to the health risks connected with human exposure to potentially hazardous wastes produced by HCEs (Adegbite et al. 2010). Although the treatment and disposal of hospital waste are intended to reduce hazards, secondary health risks may arise as a result of the release of harmful pollutants into the environment during treatment or disposal; improper handling of medical waste can have negative consequences and reduce the overall benefits of healthcare (David et al. 2014). According to a 2002 assessment of HWM procedures in 22 developing nations, 18 to 64 percent of HCEs do not use suitable waste disposal methods (WHO 2002). In developing countries like Nigeria, the most common difficulties associated with HWM are a lack of understanding of health risks, poor management practices, insufficient financial and human resources, and poor waste disposal control (David et al. 2014). Although considerable research has been done on waste creation, segregation, and disposal, there has been minimal focus on public knowledge of the possible dangers connected with medical waste and the need for staff protection in rural and semi-urban areas. There is currently a knowledge and practice gap among health professionals, which must be filled not only in the study area but also across the country (David et al. 2014). Poverty was identified by developed countries as a fundamental factor impeding African efforts to manage hazardous waste in an environmentally sound manner (Walter 2010, David et al. 2014).

MATERIALS AND METHODS

Afe Babalola University Multi-System Hospital, Ado -Ekiti was used as a case study as presented in Fig. 1. It is a 400-bed multi-system hospital that offers services such as Accident and Emergency, Surgery, Medicine, Pediatrics, Obstetrics, Gynaecology, Community Healthcare, Physiotherapy, Dental care, Fluoroscopy, Endoscopy, Colonoscopy, Gastroscopy, Bronchoscopy, Arthroscopy, Bone Densitometer, Pet-Scan, Nuclear Medicine, Echocardiography, ECG, and Treadmill Test, among others.

To effectively carry out this study, a field investigation was conducted in Afe Babalola University multi-system Hospital, Ado -Ekiti to obtain information such as the type of waste generated from each ward, the type of disposal, the time of disposal, the quantity of disposal, and so on. This information was used to analyze and characterize the profile of the HWM program adopted by the selected hospital for

Fig. 1: Afe Babalola University multi-system hospital (Field Study 2021).

their medical waste through site visits, and to complement the field investigation, a questionnaire will be administered.

Low-Cost Medical Waste Incinerator Design

The Low-Cost Medical Waste Incinerator is primarily based on modifications to the De Montfort Medical Waste Incinerator, Mark 9 designed by Professor D.J. Picken of De Montfort University, Leicester University, the United Kingdom over a period of about 8 years from 1996 to provide a low-cost and effective incinerator that could be built in almost any developing country and has been successfully applied in several African countries such as Burkina Faso, Kefalonia, and Kenya (Picken 2019, Picken et al. 2012). The incinerator to be developed is a single chamber, Batch-fed (Manual feeding), Controlled air incinerator with waste loaded once at the start of the combustion cycle, followed by combustion, ash burnout, cooldown, and ash removal as shown in Figs. 2, 3 and 4.

RESULTS AND DISCUSSION

The following is a summary of the existing HWM practices from point of creation to the dumpsite:

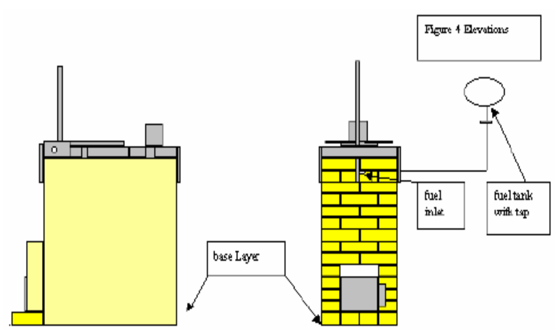

Fig. 2: De Montfort medical waste incinerator schematic diagram.

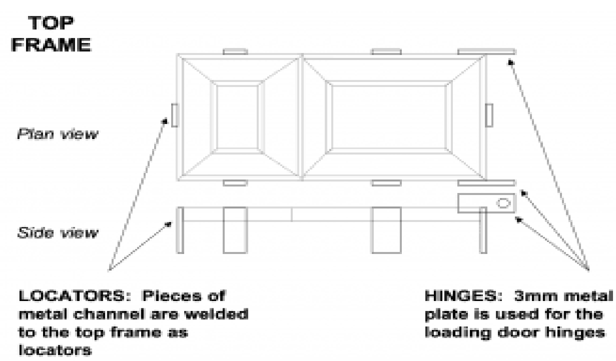

Fig. 3: De Montfort medical waste incinerator top steel frame.

1. No segregation and absence of color coding for HWM, all hospital waste is dumped into a special container at the point of creation.
2. The hospital cleaners carry the waste containers daily to the much larger bins outside the premises of the hospital.
3. The cleaning personnel with inadequate protective gear offload these larger bins onto an open truck together with municipal wastes collected at different points to be transported to the dumpsite.
4. The cleaning personnel offloads the open truck into an already-dug ditch for treatment with open fire.
5. As seen in the questionnaires, there has been some form of training given to staff (Both principal and non-principal) on hospital waste management.

The following are limitations of the existing HWM practices in the unnamed hospital (Figs. 5, 6, 7 and 8).

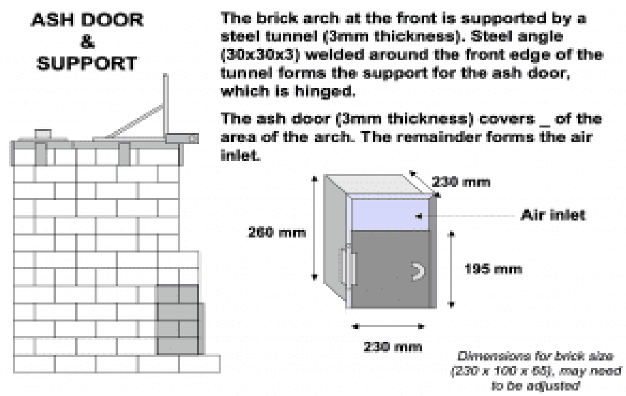

Fig. 4: De Montfort medical waste incinerator ash door and support.

Fig. 5: A hospital bed which is a point of creation of medical waste (Field Study 2020).

1. The lack of color coding and segregation is a poor practice that does not adhere to the WHO Standards for hospital waste management because all wastes are treated almost equally, which is not the case.
2. The inadequacy of protective gear of the cleaning personnel is also of great concern as they could easily be injured and get infected during the handling process

Fig. 6: Waste bins beside the hospital beds for temporary waste storage (Field Study 2021).

Fig. 7: Temporary storage bins for medical waste outside the hospital premises (Field Study 2021).

Fig. 8: Personnel offloading both medical and hospital waste unto the dump site(Field Study 2020).

3. The use of an open truck used for handling both hospital and municipal waste shouldn't be practiced. Trucks should be covered to prevent disease vectors such as flies and rats from accessing such wastes and transmitting it directly or indirectly to humans
4. While using an open fire to treat wastes could help in some cases, doing so is not environmentally or ecologically friendly because the dump site is hidden behind homes, and smoke emissions can be harmful to people and pose concerns to both occupational and public health.

Design of the Single Chamber Batch-Fed Controlled Air Incinerator

The capacity of the incinerator and burning time is estimated from the quantity of waste load generated by the hospital using the equations developed by Walter (2010). No information was obtained on the quantity of waste generated per day by the Study Hospital because the study hospital is relatively new and is not operating at full capacity. It would be reasonable to infer that the hospital's daily waste generation is underestimated, therefore an assumed value of 269 $kg.day^{-1}$.

Determination of Incinerator Chamber Capacity

The volume of waste at an optimum incinerator of 120 kg.hr-1 is dumped in the incinerator as a heap with a parabolic shape and assumed to be $5m^3$ and the following formulas are used to estimate the volume of the combustion chamber.

Volume of Combustion Chamber (V) = $L \times B \times H$

$V = 5m^3$

Length (L) to breadth (B) ratio = 1.5: 1

i.e. L = 1.5B

Height (H) = 1m (assumed for easy Incinerator operation and maintenance)

$\therefore\ 5m^3 = 1.5B \times B \times 1m$

$5m^2 = 1.5B^2$

$B \approx 1.8m$

$L \approx 2.7m$

Combustion Chamber dimensions (L × B × H) = 2.7 m × 1.8 m × 1 m

Determination of Heating Value Of Material Input

The Design Incinerator capacity was estimated at 120 $kg.hr^{-1}$. Based on a 30% waste load, it is assumed to have the following compositions (Olanrewaju et al. 2019).

1. Dry Tissue: 6%
2. Moisture: 21%
3. Ash: 3%

Table 1 gives the total heat value per hour for 30% of the waste load of 120 $kg.hr^{-1}$ (36 $kg.hr^{-1}$).

Based on a 70% waste load, it is assumed to have the following compositions (John & Swamy 2011).

1. Polyethylene: 21%
2. Polyvinylchloride: 2.1%
3. Cellulose: 36.4%
4. Ash: 10.5%

Table 2 gives the total heat value per hour for 70% of the waste load of 120 $kg.hr^{-1}$ (84 $kg.hr^{-1}$).

Total heat per hour of the waste load = 147,391.2 $KJ.hr^{-1}$ + 2,091,416.88 $KJ.hr^{-1}$

= 2,238,808.08 $KJ.hr^{-1}$

Volume of Combustion Chamber to Achieve One Second Residence Time at 1100°C

Incinerators are required to operate at a minimum residence time of 1s (residence time for gas Fumes) at operating temperature.

Combustion of Kerosene

Moisture (H_2O) at 1100ºC temperature would exist in vapor (gaseous) form, hence the total quantity of vapor output is calculated as follows:

Total H_2O Mass = Total H_2O Mass Output from Combustion of Hospital Waste + H_2O from Combustion of Kerosene

= 152.12 $kg.hr^{-1}$ + 36.35 $kg.hr^{-1}$

= 188.47 $kg.hr^{-1}$

Molar Mass of H_2O ($g.mol^{-1}$) = 18 $g.mol^{-1}$

Amount of substance, n (mol) =

$$\frac{Mass\ of\ Subastance\ (g)}{Molar\ mass\ of\ Substance\ (g/mol)}$$

Amount of H_2O (mol) = $\frac{188.47\ kg/hr \times 1000)}{18}$

Amount of H_2O (mol) = 10,468.9 mol/hr

$$V_{H_2O} = \frac{10{,}468.9\ mol/hr \times 8.20573 \times 10^{-5} m^3 atm K^{-1} mol^{-1} \times 1373\ °K}{1}$$

V_{H_2O} ($m^3.hr^{-1}$) = 1,179.48 $m^3.hr^{-1}$

V_{H_2O} ($m^3.s^{-1}$) = 0.33 $m^3.s^{-1}$

Total Volume Requirement = $V_{CO_2} + V_{N_2} + V_{H_2O}$

= 0.17 $m^3.s^{-1}$ + 1.49 $m^3.s^{-1}$ + 0.33 $m^3.s^{-1}$

= 1.99 $m^3.s^{-1}$

≈ 2 $m^3.s^{-1}$

Therefore, the active combustion chamber volume required to achieve one-second retention is $2m^3$. This active volume would be added to the calculated volume of the

Table 1: Total heat value per hour for 30% of the waste load of 120 $kg.hr^{-1}$.

Component	Empirical Formula	Input [$Kg.hr^{-1}$]	HHV [$KJ.kg^{-1}$]	Total Heat [$KJ.hr^{-1}$]
Dry Tissue	$C_5H_{10}O_3$	7.2	20,471	147,391.2
Moisture	H_2O	25.2	0	0
Ash	-	3.6	0	0
Total (30%)	-	36	20,471	147,391.2

HHV (Higher Heating Value) sourced from (John & Swamy 2011)

Table 2: Total Heat value per hour for 70% of the waste load of 120 $kg.hr^{-1}$.

Component	Empirical Formula	Input [$Kg.hr^{-1}$]	HHV [$KJ.kg^{-1}$]	Total Heat [$KJ.hr^{-1}$]
Polyethylene	$(C_2H_4)_x$	25.2	37,820	953,064
Polyvinylchloride	$(C_2H_3Cl)_x$	2.52	38,154	96,148.08
Cellulose	$C_6H_{10}O_5$	43.68	23,860	1,042,204.8
Ash	-	12.6	0	0
Total (70%)	-	84	99,834	2,091,416.88

HHV (Higher Heating Value) sourced from John and Swamy (2011).

combustion chamber (combustion chamber dimensions (L × B × H) = 2.7m × 1.8m × 1m)

The length and width of the combustion chamber are fixed, and the added height to the calculated height of 1m is calculated as follows.

$$V = L \times B \times H$$

$2\ m^3 = 2.7m \times 1.8m \times H$

$2\ m^3 = 4.86\ m^2 \times H$

$H = 2\ m^3 \div 4.86\ m^2$

$H = 0.4\ m$

∴ Overall Height of Combustion Chamber = 1 m + 0.4m

= 1.4m

∴ Minimum Combustion Chamber Dimensions (L × B × H) = 2.7m × 1.8m × 1.4m

Description of Primary Components of the Incinerator

The design of the low-cost incinerator is a modification of the De Montfort Medical Waste Incinerator, Mark 9 where necessary upgrades and removals would be made after which a comparative analysis of both designs would be shown in subsequent sections of this chapter. The following are descriptions of key components of the incinerator.

Please note that during construction, measurements may vary, all measurements are to be verified and or modified during construction.

Waste Frame

The Waste frame is designed to the dimensions of the combustion chamber (L × B × H = 2.7m × 1.8m × 1m) which is the active portion of the incinerator chamber that houses the hospital waste when placed in the Incinerator. The waste frame is made of a steel frame covered with wire gauze (Fig. 9) to facilitate the movement of ashes through the gauze after combustion and easy removal after cooldown. The legs of the waste frame are constructed to a height of 0.23m (Fig. 9) to allow easy removal of ashes after cooling down.

Combustion Chamber

The combustion chamber consists of four zones (Fig. 10) bounded by the internal walls.

Waste and combustion zone

This is where zone the hospital waste occupies which was designed for in section 4.2.2 (L × B × H = 2.7m × 1.8m × 1m)

Ash zone

The height of this zone, 0.23 m which is also the height of the waste frame legs allows for easy flow and collection of ashes during combustion and after cooling down respectively

Combustion Fumes One-second Retention Zone

The height of this zone is 0.43m and was designed (section 3.2.8) to allow for a minimum of one-second retention time of combustion fumes

Excess Air Zone

An additional spacing of 0.46 m is provided on all sides of the waste and combustion zone to allow for excess airflow from both the primary and secondary air inlets and would also serve as an allowance for the maintenance of the incinerator (Fig. 10)

Base Slab

The base slab is a 6.21m x 5.31m, 150 mm thick concrete slab reinforced with DPC reinforcement (Fig. 11). The purpose

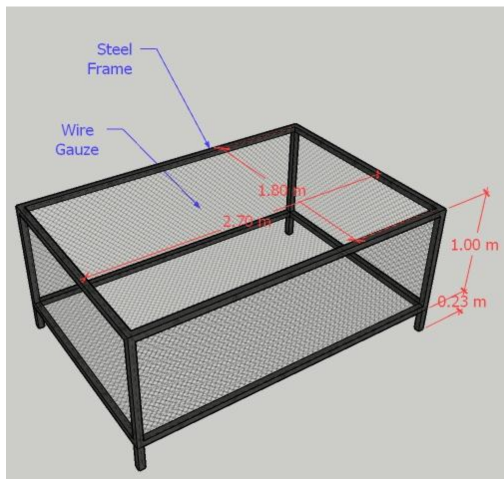

Fig. 9: 3-D Drawing of the hospital waste frame.

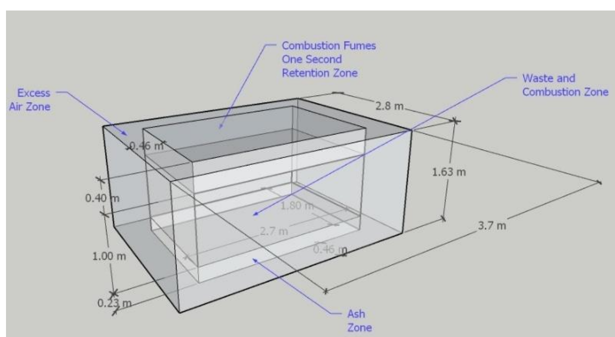

Fig. 10: 3-D Drawing of the combustion chamber zones.

Table 3: Stoichiometric oxygen requirement for combustion.

Component	Combustion Equation	Stoichiometric Air Requirement Per kg of Waste [kg.hr^{-1}]
Dry Tissue	$C_5H_{10}O_3 + 6O_2 \rightarrow 5CO2 + 5H_2O$	11.7
Polyethylene	$(C_2H_4)_x + 3O_2 \rightarrow 2CO_2 + 2H_2O$	86.4
Polyvinylchloride	$2(C_2H_3Cl)_x + 5O_2 \rightarrow 4CO_2 + 2H_2O + 2HCl$	3.22
Cellulose	$C_6H_{10}O_5 + 6O_2 \rightarrow 6CO_2 + 5H_2O$	42.3
Total	-	143.62

of this base slab is to carry the weight of the walls and all of the other components of the incinerator.

Internal Walls

The internal walls are constructed using heat-resistant bricks or blocks. They are constructed over an internal perimeter of 3.7m × 2.8m (Fig. 12) making provisions for the primary and secondary air inlet, the combustion chamber, and the fume chamber, which would be explained in subsequent sections. The purpose of the internal walls is for the combustion process, and to house the hospital waste for combustion and ashes from the combustion process.

Fig. 11: 3-D Drawing of the base slab.

External Walls

The external walls are also constructed using heat-resistant bricks or blocks to an overall height of 1.63 m. They are constructed over a perimeter of 4.91 m × 4.01m (Fig.12) also making provisions for the Primary and secondary air Inlet, the combustion chamber, and the fume chamber which would be explained in subsequent sections. An air gap clearance of 0.46 m (Fig.12) is provided to serve as heat insulation to prevent direct human contact with the heat of the combustion and heat of the internal walls.

Primary Air Inlet

The primary air inlet is a rectangular crosssection of 3.55m × 0.7m (Fig. 13) The purpose of the primary air inlet is to allow for air to enter into the combustion chamber to facilitate the proper combustion of the Hospital waste.

Secondary Air Inlet

The secondary air inlet is a steel pipe of diameter 0.3m (Fig.14). The steel pipe passes through both the external and

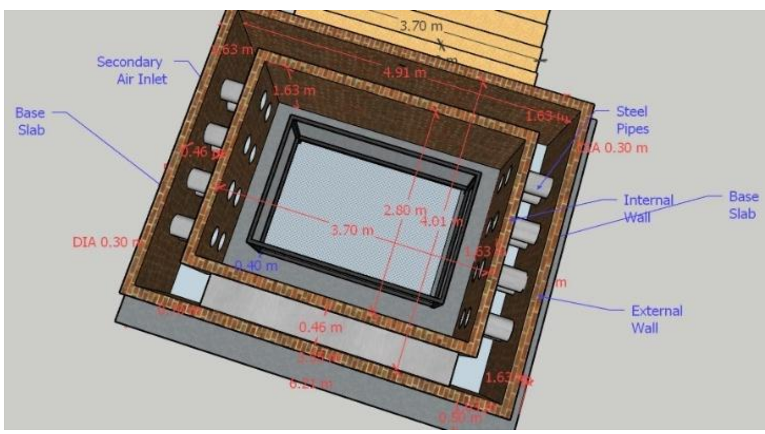

Fig. 12: 3-D Drawing of the internal and external walls.

Fig. 13: 3-D Drawing of the Primary Air Inlet.

internal walls and would be placed after both the external and internal walls have been constructed. The purpose of the secondary air inlet is to allow for additional air to enter the combustion chamber to allow for the proper combustion of the waste.

Top Slab

The top slab is a 4.31m × 5.21m, 150mm thick with openings for connecting the Incinerator Operation and Maintenance door and the fume pipe (Fig. 15). The slab is precast and reinforced with DPC reinforcements after which it is placed on top of the walls after being underlain with mortar for firm placement.

Operation and Maintenance Door

The operation and maintenance door on the top slab is constructed in a rectangular opening of 2.7m × 2.8m (Fig. 15). The operation and maintenance door is created to allow for the manual feeding of the hospital waste into the combustion chamber. The operation and maintenance door is constructed directly over the waste frame in the combustion chamber to allow the hospital waste to be placed directly into the waste frame.

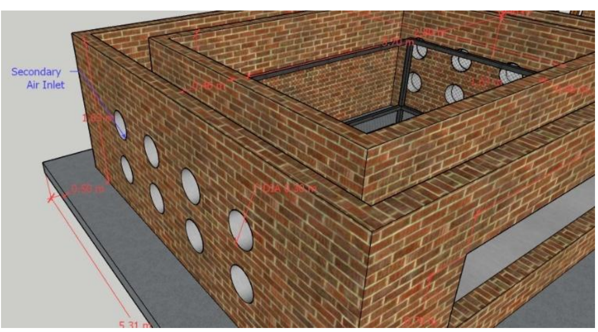

Fig. 14: 3-D Drawing of the secondary air inlet.

Fume Pipe

The fume pipe is a metal pipe of diameter 0.45 m and a standing height of 1.5 m (See Fig. 16) above the Top Slab. The purpose of the fume pipe is for the upward displacement of combustion fumes through a specific channel to the atmosphere or pollution control device.

Particle Filter

The particle filter is placed along the length of the fume pipe so that combustion fumes can pass through it and remove any tiny particles that could be hazardous to breathe in (Fig 16).

Fume PIPE and Support Stand

They are constructed to hold the fume pipe firmly to prevent it from swaying.

Fig. 17, 18 and 19 show the 3D and section drawings of the whole incinerator.

CONCLUSIONS

This study shows a similar trend of HWM practices observed in Afe Babalola University multi-system hospital in developing countries, particularly in Africa which is characterized by the absence of segregation of medical waste from point of generation. HWM practices in most developing countries do not meet WHO standards due to the lack of segregation

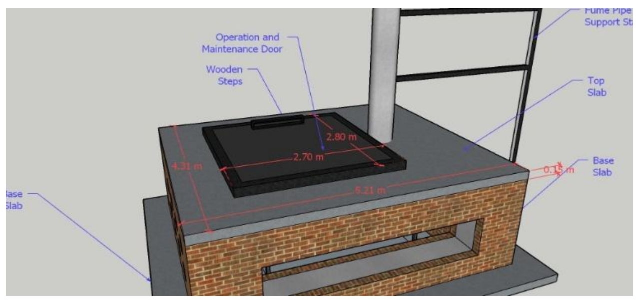

Fig. 15: 3-D Drawing of the top slab.

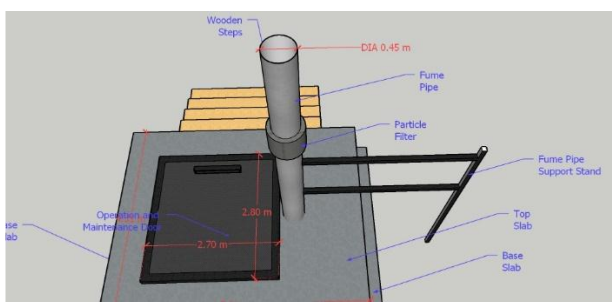

Fig. 16: 3-D Drawing of the fume pipe.

of medical waste at the point of generation, uncontrolled or open-air combustion of medical waste, collection and management of medical waste alongside municipal waste, use of inadequate protective equipment by the personnel involved in waste handling, open dumping of medical waste in un-engineered dump sites, and poorly designed incinerators if they exist for the collection, transport, and disintegration of medical wastes. There is a high risk of environmental pollution particularly air and groundwater pollution as well as a high public health risk as a result of these poor management practices. Looking at De Montfort's design of a Low-Cost Medical Waste Incinerator, his design made no provisions for the quantity of kerosene to be used for the combustion of the medical waste. The combustion chamber's capacity was determined primarily by the quantity of waste to be incinerated, essentially creating a controlled environment for the combustion of medical waste while neglecting the reactions of medical waste components with kerosene. Since it's a kerosene-fueled incinerator, it's the major cause of black smoke from the chimney. However, the design of this study takes into account the combustion interactions of kerosene with various components of medical waste and is based on a daily loading of waste. Hence it is significantly larger compared to De Montfort's design although it retained certain features of his design such as the chimney/exhaust fume, access door for cleaning and maintenance of the incinerator, a concrete base, brick or sandcrete walls as well as openings/air inlets to allow for access air during combustion.

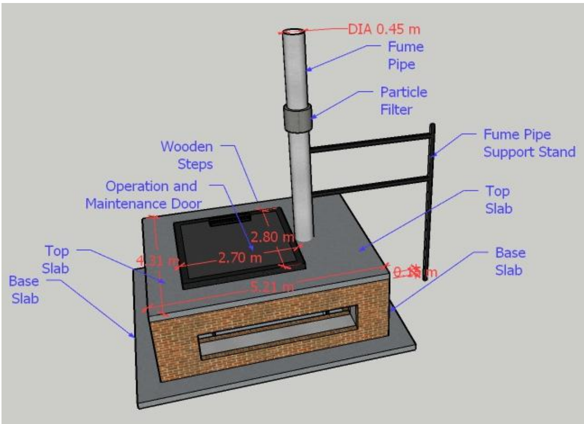

Fig. 17: 3-D Drawing of the incinerator.

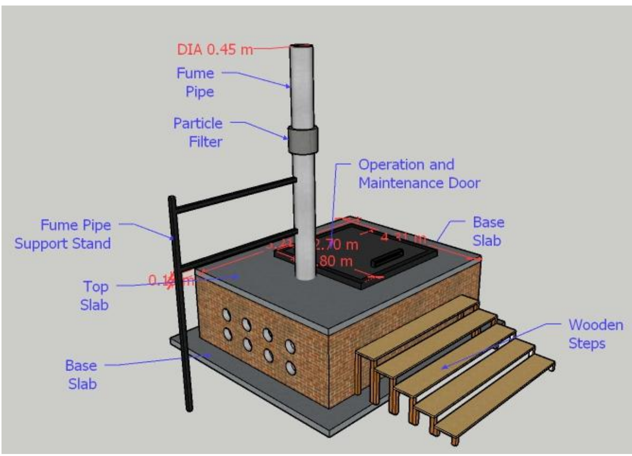

Fig. 18: 3-D Drawing of the incinerator.

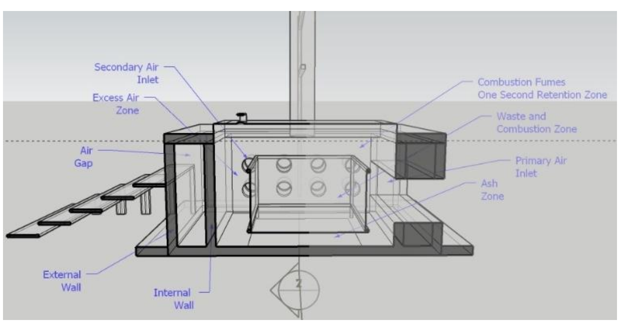

Fig. 19: 3-D, X-Ray, section drawing of the incinerator showing the combustion zone.

On completion of the design of the incinerator with an Incinerator capacity of 120 $kg.hr^{-1}$, the optimum kerosene to a medical waste ratio of 1 L of Kerosene: 3.7 kg of medical waste was determined; aside from initial construction cost, the cost of fueling daily to combust the design daily waste load of 269 $kg.day^{-1}$ would require about 73 L which would sum up to N25,550 daily or about N9.3 Million yearly which seems like a significant amount. But compared to the financial implications of the potential health risks on humans as well as pollution of the environment, far more funds would be needed to rectify such problems when they arise. The hospital would need to allocate a fixed amount of funds from income generated towards the effective management of its medical waste to meet WHO criteria, avoid the negative impacts of poor HWM procedures, and increase the international rating of the Hospital. This design is untested, further research would be required into the construction and quantitative assessment of the effectiveness of this incinerator. Both designs do not include air control devices for the fumes produced from combustion. A low-cost design that can be implemented is the design of wet scrubbers which is effective towards this end.

RECOMMENDATIONS

The state of HWM practices in developing countries especially in Nigeria needs a lot of improvement and the following are recommendations for achieving an improved state of HWM practices in Nigeria.

1. The Nigerian Government should create and enforce laws eradicating the dumping of medical as well as municipal wastes in un-engineered dumpsites; specific dumpsites should be made available and providing fencing to ward off scavengers.
2. All waste-handling staff should and must be outfitted with full safety gear.
3. Regulatory bodies must impose segregation practices in all healthcare facilities from the point of creation to the final disposal site.
4. Ensuring strict compliance with WHO standards on the collection, transport, and disintegration of medical waste
5. Hospitals should adequately allocate both human and financial resources in all HWM operations
6. Regular training and orientation of all staff involved in HCEs on HWM practices

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