EXPERIMENTAL DESIGN AND FABRICATION OF DOMESTIC WATER HEATING FROM SOLID WASTE INCINERATOR

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ABSTRACT
Solid wastes arise from human activities- domestic, commercial, industrial etc. The consequences of domestic waste are felt by both humans and the environment. Incineration is a waste treatment technology that involves the destruction of waste by controlled burning at high temperatures. The energy generated by this system in form of heat can be optimized via energy recovery technology in incinerator systems which is incorporated in this study and used for the purpose of domestic water heating. This research work is aimed at studying solid waste incineration, designing and fabricating an incinerator with energy recovery by applying heat exchanger technique. The design quantity of heat generated from calculations is 20 KW from combusting 4.76Kg/h of the municipal solid waste which would be required to heat 0.01244kg/s (0.01244litre/sec) of water from 32.5-70°C. From test results obtained, the maximum temperature obtained was 67.3°C, which is lesser than the design temperature of 70°C due to the presence of heat losses. Further more, when in used it will reduce power consumption for water heating and aid solid waste management.

Keywords: Solid waste, Water Heating, Incinerator, Domestic

NOMENCLATURE
c_p – Specific heat capacity at constant pressure (kJ/kgK)
CV - Caloric value (kJ/kg)
D, d - Diameter (m)
h – Coefficient of heat transfer (W/m^2K)
LMTD - Logarithm Mean Temperature Different (^0C, K)
- mass flow rate of fluid (kg/s)
MSW - Municipal solid waste
Nu - Nuselt Number
Pr - Prandt Number
Q - Amount of heat required (kW)
Re - Reymolds Number
U - Overall Coefficient of heat transfer (W/m^2K)
v – Kinematic viscosity (m^2/s)
ρ – Density (kg/m^3)
K –Thermal Conductivity (W/mK)

Subscript
f – Furnace
fg -Flue gas
uf - Unburnt fuel
w - water

1.0 INTRODUCTION

Solid waste management is a major responsibility of State and Local government environmental agencies and has emerged as one of the greatest challenges facing the agencies. In Nigeria, the volume of solid waste being generated continues to increase at a faster rate than the ability of the agencies to improve on the financial and technical resources needed to parallel this growth. Solid waste management in Nigeria is characterized by inefficient collection methods, insufficient coverage of collection system and improper disposal of solid waste.

Most developing countries (Nigeria inclusive) have solid waste management problems different from those found in industrial countries in terms of composition, density, political and economic framework, and waste amount, access to waste for collection, awareness and attitude. The wastes are heavier, wetter and more corrosive in developing cities than developed cities(Ogwueleka, 2009).

In developing countries, local authorities spend 77-95% of their revenue on collection and balance on disposal but can only collect almost 50-70% of municipal solid waste.(Ogwueleka, 2009) Waste is defined as any object that may or may not have served its intended use and the owner is not ready to continue to keep it and that he/she is ready to discard it if possible,(Igbinomwanhia, 2010). Waste may also be defined as left over or already used items waiting for reuse or disposal, (Audu, 2007). Certain definitions define waste as useless, but advances in technology, further studies into urban development and waste management has proved that waste can be useful. All over the world, communities handle their waste or trash differently. Some common methods of managing their waste include land filling, recycling and composting. Other communities strongly embark on waste reduction and litter prevention/ control aimed at reducing the production of waste in the first place. Some communities also engage in waste to energy plants and hazardous waste disposal programmes.

It refers to a variety of discarded materials, not liquid or gas that is deemed useless or worthless. Solid waste means any garbage, refuse, discarded materials including solid, semi-solid composition resulting from industrial, commercial, mining and agricultural operations, and from community activities, but does not include solid or dissolved materials in domestic waste sewage or solid or dissolved materials in irrigation return flows or industrial discharges that are point sources.(United States Environmental Protection Agency, 2010)

The first attempts to dispose of urban refuse through combustion in a furnace are reported to have taken place in the north of England in the 1870s. By the turn of the century, emphasis was placed on the development of furnaces capable of burning solid wastes. During this time, a number of communities found incineration to be a satisfactory and sanitary method of waste disposal. The reason for the satisfaction lay in the fact that the main objective was to achieve maximum volume or weight reduction. Little or no concern was had for energy recovery or for control of air pollution from incinerators.

One attractive aspect of waste combustion is its potential for energy recovery. Heat recovery from waste incinerators can be accomplished in much the same way and is often considered as an approach for reducing waste management costs.

Years ago, incinerators were designed to burn waste that had a low heating value. The reason was primarily to accommodate wastes with high moisture content. Consequently, features were incorporated that were designed to: 1) dry and ignite the refuse, and 2) deodorise the off gases. Little or no waste heat was available for energy export. As the composition of municipal waste in industrially developed countries changed (i.e., substantial paper and plastic content, small putrescible fraction), the heating value of the solid waste increased. To accommodate the increase, the designers of modern incinerators include in their designs provision for the utilisation of excess energy.

The consequences of domestic waste are felt by both humans and the environment. Waste if not properly checked can lead to; use of landmass as dumpsters, reduced quality of air, blockage of drainages and health risks. The project is a relevant research in the reduction of dry waste deposits (combustible) which have reached a critical point in the country. The used of energy recovery incinerator is significant in areas of environmental studies, domestic usage and conservation of energy.

Incineration is a treatment technology involving the destruction of waste by controlled burning at high temperatures. USEPA (2010) defined incinerations as the “high-temperature combustion of waste” as stated in Xiao et al. (2104). The first incinerators for waste disposal were built in Nottingham by Manlove, Alliott and Co. Ltd. in 1874 to a design patented by Albert Fryer. They were originally known as destructors. Modern technologies have refined incineration from a disposal only process to an energy generation process; therefore incineration is the thermal process wherein the combustive components of a solid stream are thermally oxidized to produce heat energy that can be used to create steam for generating electrical power, for industrial process or for district heating.(Bary Wilson, 2013)

One of the most important processes in engineering is the heat exchange between flowing fluids (Obanor, 2014). Heat exchangers are devices that facilitate the exchange of heat between two fluids that are at different temperatures while keeping them from mixing with each other.(Cengel, 2002). In heat exchangers, the temperature of each fluid changes as it passes through the exchanger, and hence the temperature of the dividing wall between the fluids also changes along the length of the exchanger. Heat exchangers are commonly used in practice in a wide range of applications, from heating and air-conditioning systems in a household, to chemical processing and power production in large plants (Prasad, 1996; Osafehinti et al., 2014).

Most research works on Waste to Energy (WTE) have focus on electricity generation. Such works need huge capital cost to execute them. It will be ideal to look into hot water generation from waste, which is less capital intensive. Productions of hot water in the country are from various sources such as fossil fuel and electricity. To develop sustainable energy systems, renewable energy is perhaps the most direct way of moving away from fossil fuels. Municipal solid waste been classified as locally available renewable resource that can aid sustainable energy system. Unachukwu and Anayanwu (2010) reported in their work that 25% of most urban waste in Nigeria is combustible materials, which are suitable for incineration process. The aim of this study is to design and fabricate water heating solid waste incinerator for domestic purpose.

2.0 METHODOLOGY

2.1 DESC RIPTION OF THE INCINERATOR

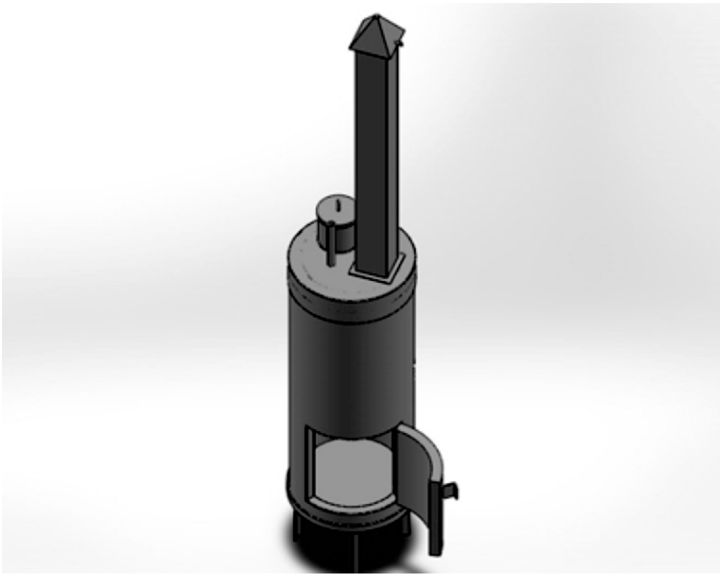

Figure 1: Cylindrical natural convection process water heating incinerator.

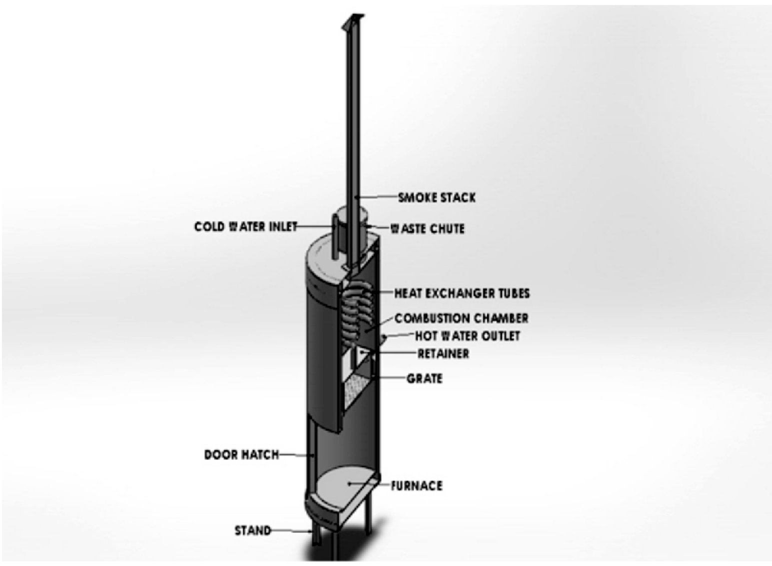

Figure 2: Sectional view of cylindrical natural convection process water heating incinerator.

This cylindrical incinerator is made up of external casing constructed of mild steel. Within the incinerator there is a combustion chamber which is located above the furnace. The base of the combustion chamber is a mild steel grate over which the waste is burnt. A door hatch serves as a cover for the entry into the furnace. Holes are made in the combustion chamber to aiding combustion. Sawdust which is the insulation material also serves as the primary source of fuel and is packed into the furnace through the top. The waste is then packed into the combustion chamber through a chute situated on top of the incinerator. The cold water inlet pipe runs from the top and is connected to a retainer situated within the combustion chamber. The tubes within the shell of the heat exchange section are made of copper. The retainer serves as a vessel where enough heat is accumulated by the water before leaving the incinerator to the hot water storage vessel.

2.2 DETAILED DESIGN

2.2.1 DESIGN CONSIDERATIONS

The project is intended to cater or have the ability to do the following:

a) Incinerate a certain waste load or charge.
b) The incinerator should be able to heat a given volume of water, the volume of water to be heated in this project is 45liters.
c) Completely combust the waste using the appropriate fuel.

2.2.2 DESIGN SPECIFICATIONS

These specifications describe the various performance characteristics of the incinerator and they are presented in quantitative values. Below are the pre-design or set values of the incinerators with energy recovery for heating water are follows:

1. Temperature of heated water at the exit of the incinerator: 60-70^{o}C
2. Type of waste for incineration : Solid waste
3. Overall size of the incinerator;
   a) Weight :60 Kg
   b) Dimensions : 450mm × 2240mm
4. Type of fuel used : Saw dust (preliminary fuel)

2.3 MATERIAL SELECTION

The selection of materials is very important in the design and construction of any machinery as it affects the reliability and availability of the machinery. It is even more relevant when the materials that make up these components are subjected to high temperatures. The materials are selected on the following criteria;

a) Highest Temperature Limit (maximum temperature)
b) Resistance to Corrosion
c) Market Availability
d) Thermal Conductivity

The components, materials and the basis for their selection are presented in tabular form as shown in Table 1.

	COMPONENTS	MATERIAL	BASIS FOR SELECTION
1	Outer and inner walls of the incinerator	Mild steel	• High thermal conductivity • High tensile stress • High thermal stress resistance
2	Heat exchanger or Water tubing	Copper	• Good thermal conductivity • Resistance to corrosion • Ease of malleability • High thermal conductivity
3	Lagging / Insulation	Saw dust	• Low thermal conductivity • Availability and relative cheapness compared to other insulating materials • Less weight
4	Grate	Mild steel	• Very high melting point • High thermal resistance
5	Hopper	Mild steel	• High melting point • High thermal resistance

2.4 CALCULATIONS AND ANALYSIS OF COMPONENTS

The amount of heat needed to raise the temperature of a fluid can be determined using Equation (1).

$$Q = \dot{m}c\Delta T \quad (1)$$

The quantity of heat liberated in the furnace can be calculated applying Equation (2).

$$Q_f = Q_{fg} + Q_w + Q_{uf} \quad (2)$$

The heat energy potential of the burnt waste and unburnt waste can be determine applying Equations (3) and (4) respectively.

$$Q_f = m_{msw} CV_{msw} \quad (3)$$

$$Q_{uf} = m_{uf} CV_{msw} \quad (4)$$

The feed water temperature of 32.5°C was determined experimentally (Atare et al., 2014). The properties of water at 32.5°C were obtained from Roger, and Mayhew (1995), which are shown in Table 2.

Table 2: Properties of Water and Flue Gas

Parameters	Water	Flue gas
Density ,ρ (Kg/m^3)	994.827	0.51475
Thermal conductivity ,k (W/mk)	621.5×10^3	5.15986×10^{-2}
Kinematic viscosity ,v (m^2/s)	7.65×10^{-7}	6.40342×10^{-5}
Prandtl number ,Pr	5.095	0.6835
Velocity, V (m/s)	0.107	10
Specific heat capacity, c_{pw} (kJ/kgK)	4.18	

The volume flow rate of the water from a range of experimental values is $0.0000125m^3/s$
Mass flow rate of water in the design is 0.01244Kg/s
Volume of water to be heated = 45 litres = $0.045m^3$
Mass of water at $32.5^oC = 994.827 \times 0.045 = 44.8Kg$
The rate at which heat is used to heat water in the tube is $0.01244 \times 4.18 \times (40-25) = 0.78KW$
Coefficient of heat transfer from tube wall to hot water
Reynolds number, $Re = d\,(V/v)$ (5)
Nusselt number, $Nu = 0.021Re^{0.89}Pr^{0.43}$ (6)
Therefore the coefficient of heat transfer from the tube wall to the water is expressed in Equation (7).

$$h_w = Nu \times \frac{k}{d} \quad 1495.86 W/m^2k \qquad (7)$$

Using the values of water in Table 2 and applying Equations (5) – (7), the coefficient of heat transfer from the tube wall to the water was calculated as $h_w = 1495.86\ W/m^2K$.
Heat of flue gas, $Q_{fg} = m_{fg}C_{pfg}\,(T_{fg} - T_o)$ (8)

The maximum temperature (T_{fg}) of flue gas attained in the furnace was estimated as 850K. The reference temperature of the exit flue gas was taken as 523K (Pershing et al., 1993). The mean value was used to determine its properties as shown in Table 2.

The heat transfer coefficient in the flue gas to water tube-walls

$Nu_{fl} = 0.26\,Re^{0.65}Pr^{0.35}$ (9)

The heat transfer coefficient of flue gas was determined to be 101 W/m^2K applying Equations (5), (7) and (8) using the data from Table 2.
The overall heat transfer of flue gas to tube walls was determine by using Equation (10)

$$U_s = \left(\frac{1}{h_w} + \frac{1}{h_{fg}}\right)^{-1} \qquad (10)$$

$= 94.612\ W/m^2K$

The material used for the tubing in the Heat Exchanger is Copper. In the heat exchanger tubing the temperature of water is increased from 32.5-70°C or 305.5K - 343 K

The heat supplied to the boiling tube is given by (Cengel, 2002) as shown in Equation (11).

$$Q = U_s A_s \,(LMTD) \tag{11}$$

The logarithm mean temperature difference (LMTD) is evaluated using Equation (12).

$$LMTD = \frac{(T_{hin} - T_{cout}) - (T_{hout} - T_{cin})}{In\left(\frac{T_{hin} - T_{cout}}{T_{hout} - T_{cin}}\right)} \tag{12}$$

$$A_s = \frac{Q}{U_s LMTD} \tag{13}$$

$$l = \frac{A_s}{\pi d} \tag{14}$$

$$n = \frac{l}{D} \tag{15}$$

The areas, length of the tubes and number of turns or pass was determine as $0.0603m^2$, 0.8m and 4 turns applying Equations (13) to (15) respectively.

From literature, the volumetric heat release rate for municipal refuse, $q_v = 0.18 \times 10^6$ $Kcal/hrm^3 = 209.29\ KJ/sm^3$ (Niessen, 2002) and

$$q_v = \frac{Mw \times CV}{V} \tag{16}$$

where V = minimum volume of incinerator, M_w = charging rate of the waste

The volume of the combustion chamber is $\pi r^2 h$, where d = diameter of the combustion chamber = 450mm and h = height of the combustion chamber =600mm

Therefore, $V = \pi\,(0.225^2 \times 0.60) = 0.0954m^3$.

Inputting the values in the Equation (16), the charging rate of the waste is 0.001322Kg/s or 4.759 kg/hr. The amount of heat required was determined to be 19.6 kW by applying Equation (3). The amount of heat transferred to the water to increase temperature to 32.5 - 70°C was calculated as 2.34kW from Equation (1).

2.5 MANUFACTURING SPECIFICATIONS

The specifications chosen from the range of detailed design specifications are shown in Table 3, which the final design of the components was based on.

Table 3: Bill of Engineering Measurement and Evaluation

S/N	Part name	Material	Dimension	Quantity
1	Insulation	Saw dust		-
2	Steam – Water tubing and fittings	Copper	1 length-2 metres	1
3	Water reservoir			1
4	Heat exchanger shell	Mild steel	450 by 600 mm	1
5	Hinges			4
6	Grate		380mm	1
7	Sheet metal	Mild steel	2300by 1500mm	1
8	Spray painting			
9	Fuel compartment		440 by 600 mm	1
10	Base stand		280mm 470mm	1

2.6 MANUFACTURING PROCESSES

MILD STEEL GRATE: The grate at the bottom of the combustion chamber is made of mild steel. The mild steel materials were welded across into a mesh with the use of a welding machine and electrodes and to a dimension of 380 mm diameter and 5mm thickness specified for the grate.

COMBUSTION CHAMBER: The mild steel sheet was cut to a dimension of 450mm diameter and height of 600mm required for the combustion chamber compartment. Thereafter, it was rolled using a rolling machine and welded the ends welded using an arc welding machine and gauge 12 electrodes. For the top cover of the chamber we made a hole of 25.4 mm diameter for entry of the tube as well as a 160mm by 160mm hole for the stack and 150mm diameter for the waste chute.

HEAT EXCHANGER AND TUBING: The heat exchanger comprises tubing made of copper. The mild steel material was measured out with a measuring tape cut and turned to a dimension of 450mm diameter and height of 280mm and welded with an arc welding machine and gauge 12 electrodes to form the frame at the heat exchanger section. The purchased copper tubes were turned in loops by hand with the use of a cylindrical guide and the outlet and inlet extended from the heat exchanger. The inlet protrudes vertically downwards and formed into loops and the outlet protruding vertically downwards to the retainer.

RETAINER: The retainer is made of stainless steel. The stainless steel material was measured and cut out with a cutting machine and holes of 25.4mm for entry and exit were made for the tube. The ends of the stainless steel material were then welded with welding machine and stainless steel electrodes to form the retainer component.

SMOKE STACK: The smoke stack is of square cross section and is made from mild steel. The mild steel material was measured with a measuring tape, then cut out to a dimension of height 1200mm and width of 640mm, folded and welded to form the square shape cross section. The stack was then fastened to the top cover of the incinerator with nuts and bolts.

FRAME: The frame of the Incinerator is made of mild steel with provision for lagging with sawdust. The mild steel material was measured with measuring tape, cut out with cutting machine, turned and rolled to the dimension of height 880mm by 480 mm diameter. Holes were also made at the upper combustion chamber compartment for air entry and tube exit to the tap. The door hatch for the furnace was measured out, cut and turned to a dimension of height 370mm and thickness 40mm to accommodate the saw dust lagging and afterwards joined to the mild steel frame with the aid of hinges and screwed to the material. The bottom of the mild steel frame was then sealed and supports were also welded for the base of height 280mm by 470mm.

3.0 RESULTS AND DISCUSSION

After fabrication was completed, the incinerator was tested to check for performance and any design deviations. This test was carried out after charging the saw dust and dried solid waste into the incinerator. The solid waste was ignited to initiate combustion after which water was passed into the copper tubing. The test was carried out over a one hour period over which the mass of the solid waste depleted gradually and readings were taken of the temperature of water at the outlet at intervals of ten minutes i.e. six readings over the test period at different time. Results obtained are presented in Figure 3. The readings taken showed that the temperature of water at the outlet was increasing with time, but dropped at the end of the testing period as shown in Figure 3; due to the reduction in the mass of the waste, thereby reducing the amount of heat supplied to the hot water.

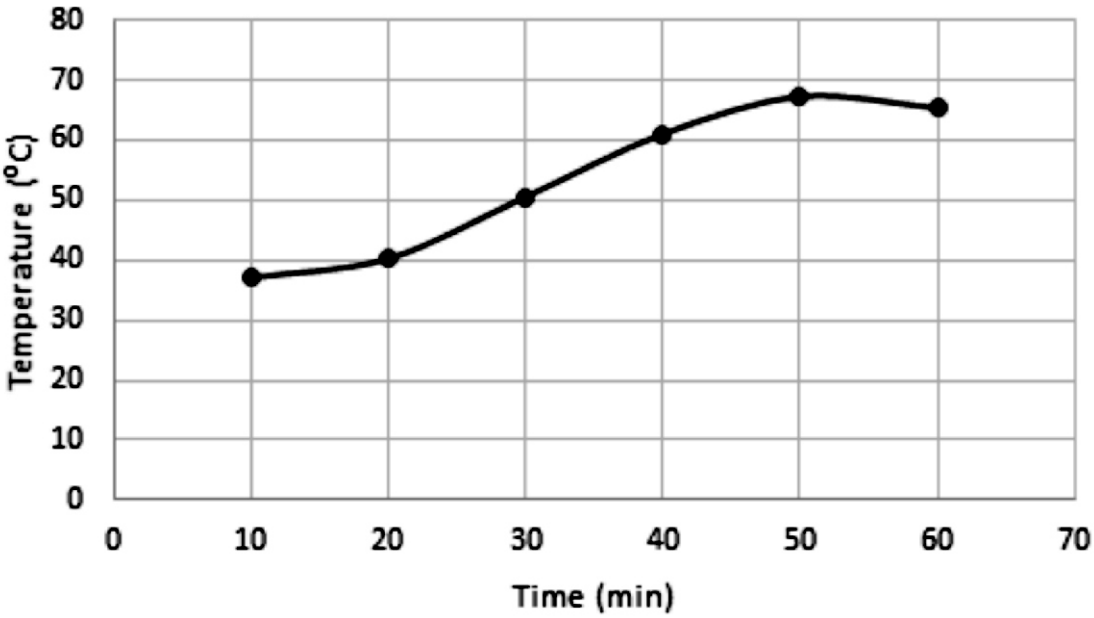

Figure 3: The temperature of hot water at outlet against time for heating

Energy recovery is very important in Waste to Energy technology that utilizes the heat energy given out from the incinerator; in this work the waste was limited to dry solid waste. Developed countries harness this energy to supplement power production, while developing nations like Nigeria are yet to harness the potential of this technology.

In this study, a design of an incinerator with energy recovery was developed. Conceptual design was stated; design specifications and other design parameters of the selected design were also stated. The incinerator is basically made from mild steel (for the inner and outer walls), saw dust (for lagging/insulation) and copper tubing connected to the retainer is placed in the combustion area.

This incinerator was designed to take in water at room temperature and the discharge water at the exit of the incinerator was70 °C. To achieve this about 4.8Kg/hr. of dry solid waste was used to heat the water. Saw dust was used as insulation between the inner and the outer walls of the incinerator body.

The results from test conducted showed that over a period of 60 minutes, the maximum temperature obtained was 67.3°C, although there was a drop in temperature after 50 minutes by 1.9°C to 65.4°C.

This study and design has shown that it is viable and should be looked into seriously as it would reduce power usage in heating water and aid in effective solid waste management. During the course of this work challenge encountered was difficulty in proper coiling of the tube.

4.0 CONCLUSION AND RECOMMENDATION

The energy recovery incinerator was designed and fabricated using available local resources. The result obtained from the test carried out shown that the maximum temperature of hot water was 67.3 ^{0}C, which is 2.7 ^{0}C less than the design value. This revealed that the designed incinerator is viable for hot water production . it therefore ,recommended for domestic purpose for it will help to reduce power usage for heating water and reduce the menace caused by solid waste in the environment.

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