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The Design and Construction of a Step Grate Incinerator

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Abstract- This paper presents the design and fabrication of an incinerator meant to thermally treat (i.e. combust) domestic waste for the purpose of reducing its volume and destroying hazardous substances or pathogens present in the waste. A step grate package incinerator with a capacity of 100 kg/day was designed and constructed to combust domestic solid waste which otherwise cannot be economically recycled. The mass balance of the equipment was done to determine the amount of combustion air needed to completely burn the waste; likewise the heat balance was done to determine if an auxiliary burner would be needed. The performance test carried out on the waste – plastic, paper, rubber, leather, textile, wood and garbage – reveal a percentage decrease in volume between 78% – 95%.

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Abstact- This paper presents the design and fabrication of an incinerator meant to thermally treat (i.e. combust) domestic waste for the purpose of reducing its volume and destroying hazardous substances or pathogens present in the waste. A step grate package incinerator with a capacity of 100 *kg/day* was designed and constructed to combust domestic solid waste which otherwise cannot be economically recycled. The mass balance of the equipment was done to determine the amount of combustion air needed to completely burn the waste; likewise the heat balance was done to determine if an auxiliary burner would be needed. The performance test carried out on the waste – plastic, paper, rubber, leather, textile, wood and garbage – reveal a percentage decrease in volume between 78% – 95%.

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I. Introduction

The efficient management of solid waste is very important to public health and well-being of urban residents(Ernst, 2008). In most cities in the developing world, several tons of municipal solid waste is left uncollected on the streets each day, interfering with the free flow of drainage, creating feeding ground for pests that spread diseases and creating an enormous health and infrastructural problems. Municipal solid waste management is an important part of the urban infrastructure that ensures the protection of environment and human health (Sandna, 1982).

The degradation of the environment caused by inefficient disposal of waste can be expressed by the contamination of soil, surface and ground water through leachate; the spreading of diseases by different vectors like birds, insects and rodents. There is also the uncontrolled release of methane by anaerobic decomposition of waste and air pollution by open burning of waste. The sustainability of the land filling system has become a global challenge due to increased environmental concerns. Growing public opposition together with unavailability of land is one of the reasons why obtaining sites for new landfill is becoming increasingly difficult. Locating a landfill far away from the urban area or far away from the source of waste generation increases transfer costs and additional investments for the infrastructure of roads, hence intensifying the financial problems of the responsible authorities. Common problems for Municipal Solid Waste (MSW) management in the cities include institutional deficiencies, inadequate legislation and resource constraints (Magrinho*et al*, 2006). Long and short term plans are inadequate due to capital and human resource limitations. There is a need to practice integrated solid waste management approach such as: Incorporation of more environmental and economic friendly concepts of source separation; recovery of waste; legitimization of the informal systems; partial privatization and public participation (Kreith, 1994). Although some governments have formulated policies for environmental protection, they were only implemented in the national capital cities. In rural areas, open dumping is still considered the most popular method of solid waste disposal (Oyelola*et al*, 2011).

The challenges of urban solid waste management can be addressed by building an incinerator to thermally treat the solid waste as a part of the integrated waste management method. The incineration of solid waste reduces the waste to about 10% to 15% of its original volume, destroys all the harmful substances contained in the waste, and so it is very ideal in big cities where the availability of land is very scarce(Knox,2005). The equipment can also be incorporated with a heat recovery device to produce steam for process industries and power plants. The process of incineration involves taking into consideration the temperature the combusting gases reach, the length of time the gases remain at elevated temperatures, how well the air and the gases are mixed and whether there is adequate oxygen to permit complete combustion (Niessen, 2014). The incineration of solid waste is imperative in a situation whereby the waste is so degraded to such extent that recycling is no longer cost effective. The aim of this work is to design and construct a step grate incineration for burning MSW especially those with high moisture content like garbage (70%) and pathological waste (85%).

II. Methodology

The detail design of the incinerator was done to calculate the mass and heat balance of the system, these were used to determine the size of the blower and also determine if an auxiliary burner is needed. The construction of the equipment was done with mild steel and refractory bricks.

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a) Selection of the Force Draft Fan (blower)

The selection of the draft fan was done based on the calculation of the mass balance to determine the size of the blower needed to introduce combustion air into the system. Table 1 shows the combustion equation of the various waste types and the stoichiometric airrequirement to completely burn the waste.

b) Selection of the Auxiliary burner

The heat balance was done to determine if an auxiliary burner will be needed to sustain the combustion process at a temperature of 600°*C*.The heat balance in the combustion chamber of the incinerator is shown in the diagram of Figure 1while Table 2 shows the heat balance for the incinerator.

c) Performance Test

The performance test of the incinerator was carriedout to estimate the combustion efficiency of the equipment given by the formula in equation 1. The test was done using different types of waste and taking into consideration the amount of combustion air required and the volume reduction of the waste after the incineration process as shown in Table 3.

$$\eta = \frac{CO_2}{CO_2 + C_O} \times 100\% \qquad (1)$$

III. Results and Discussions

Table 1 shows the combustion equation of the various solid wastes and the amount of stoichiometric air needed to completely burn the waste. However, in the course of introducing air into the combustion chamber, a considerable amount of the air passes through without reacting with the waste, either because of the high speed with which it is introduced or the compactness of the waste which impede the proper diffusion of air into the waste. Therefore, an excess amount of air (30%) was supplied to compensate for the fugitive air that passes through the system without reacting with the waste. The calculation of the heat balance in Table 2 shows that 61,541*kJ/h* of heat energy (contained in the flue gas) exits the incinerator into the atmosphere. This heat energy can be used to dry a high moisture waste like pathological waste (85% moisture content) or garbage (70%) placed in the drying grate of the incinerator. The performance test in Table 3 reveals volume reduction of waste between the ranges of 78% - 95%. The ash produced after the combustion process can be safely land filled or used as construction material in the civil engineering industry. The combustion efficiency of the system is 86.5%, this is slightly higher than the 85.2% efficiency result obtained by Cyril et al (2016) from the design and development of a portable

IV. Conclusion

The thermal method of solid waste management (incineration) is one of the best methods of treating or disposing of waste as long as the emission produced is not harmful and within the range permissible by federal and state regulations. In order to avoid black smoke coming out of the chimney which is a sign of incomplete combustion or inadequate supply of air, it is important that an appropriate excess air ratio be used to ensure effective burnout of the combustibles in the chamber, suppressing the formation and emission of pollutants. Furthermore, the heat produced from the process can be captured by a heat recovery device (boiler) to produce steam for process industries or thermal power station. Also the incineration of solid waste reduces harmful substances to ash which can be safely landfilled or used as construction material.

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Tables

Table 1 : The combustion equation and the stoichiometric air requirement

Waste (1.0 *kg*)	Combustion equation	Stoichiometric air requirement (*perkg waste*)
Paper	$C_6H_{10}O_5 + 6O_2 \longrightarrow 6CO_2 + 5H_2O$	5.16
Rubber	$C_5H_8 + 7O_2 \longrightarrow 5CO_2 + 4H_2O$	14.32
Plastic	$C_2H_4 + 3O_2 \longrightarrow 2CO_2 + 2H_2O$	14.9
Wood	$4C_{10}H_{15}O_7 + 41O_2 \longrightarrow 40CO_2 + 30H_2O$	5.74
Leather	$C_5H_8O_{0.75}N_{0.71}S_{0.013} + [4.64O_2 + 4.64(79/21)N_2] \longrightarrow 5CO_2 + 4H_2O + 0.013SO_2 + 17.8N_2$	7.05
Textile	$C_{4.6}H_{6.6}O_2N_{2.9}S_{0.0047} + [5.25O_2 + 5.25(79/21)N_2] \longrightarrow 4.6CO_2 + 3.3H_2O + 0.0047SO_2 + 21.2N_2$	7.76
Garbage	$C_6H_{9.6}O_{3.5}N_{0.28}S_{0.2} + [6.4O_2 + 6.4(79/21)N_2] \longrightarrow 6CO_2 + 4.8H_2O + 0.2SO_2 + 24.22N_2$	3.29
$Total\ air\ required$ (at 30% excess air) $= (\%\ excess\ air \times stoich.air) + stoich.air$ $m_{air} = (0.3 \times 58.22) + 58.22$ $= 75.69\ kg$		

Table 2 : Heat balance for the incinerator

Heat input (*kJ/kg*)		Heat output (*kJ/h*)	
Paper	14,085	Radiation loss = 5% of total heat available= 5% × 132,100	6,605
Plastic	33,712	Heat to ash $= mC_P(T_g - T_C)$ $= 0.35 \times 0.831 \times (600 - 25)$	167.23
Rubber	22,197	Heat to dry combustion product= mC_PdT $= 98.6 \times 1.086 \times (600 - 25)$	61,541
Textile	17,476	Heat to moisture $= (mC_PdT) + (mH_V)$ $= [7.92 \times 2.347 \times (600 - 25)] + [7.92 \times 2460]$	30,173
Wood	16,580		
Leather	19,050		
Garbage	9,000		
Total	132,100		94,486.23

Net Balance $= Q_0 - Q_1$

$= 132{,}100 - 94{,}486$

$= 33{,}613.8\ kJ/h$ (heat required to maintain the incinerator at 600°C)

Table 3 : Performance test of the incinerator

Type of waste (10 *kg*)	Stoichiometric air requirement (*perkg waste*)	Volume reduction (%)
Paper	51.6	95
Textile	77.6	92
Wood	57.4	96
Rubber	143.2	80
Leather	70.5	81
Plastic	149.0	78
Garbage	32.9	85

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Figures

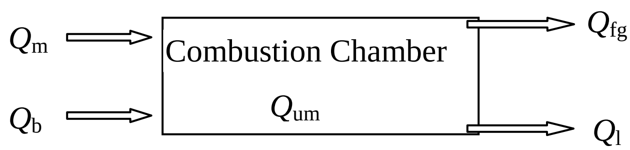

Figure 1 : Heat balance of the incinerator

Q_m: Heat energy of the waste material
Q_{um}: Heat energy retained in the unburned waste
Q_{fg}: Heat energy of the flue gas
Q_l: Heat loss to the surrounding
Q_b: Heat supplied by the auxiliary burner

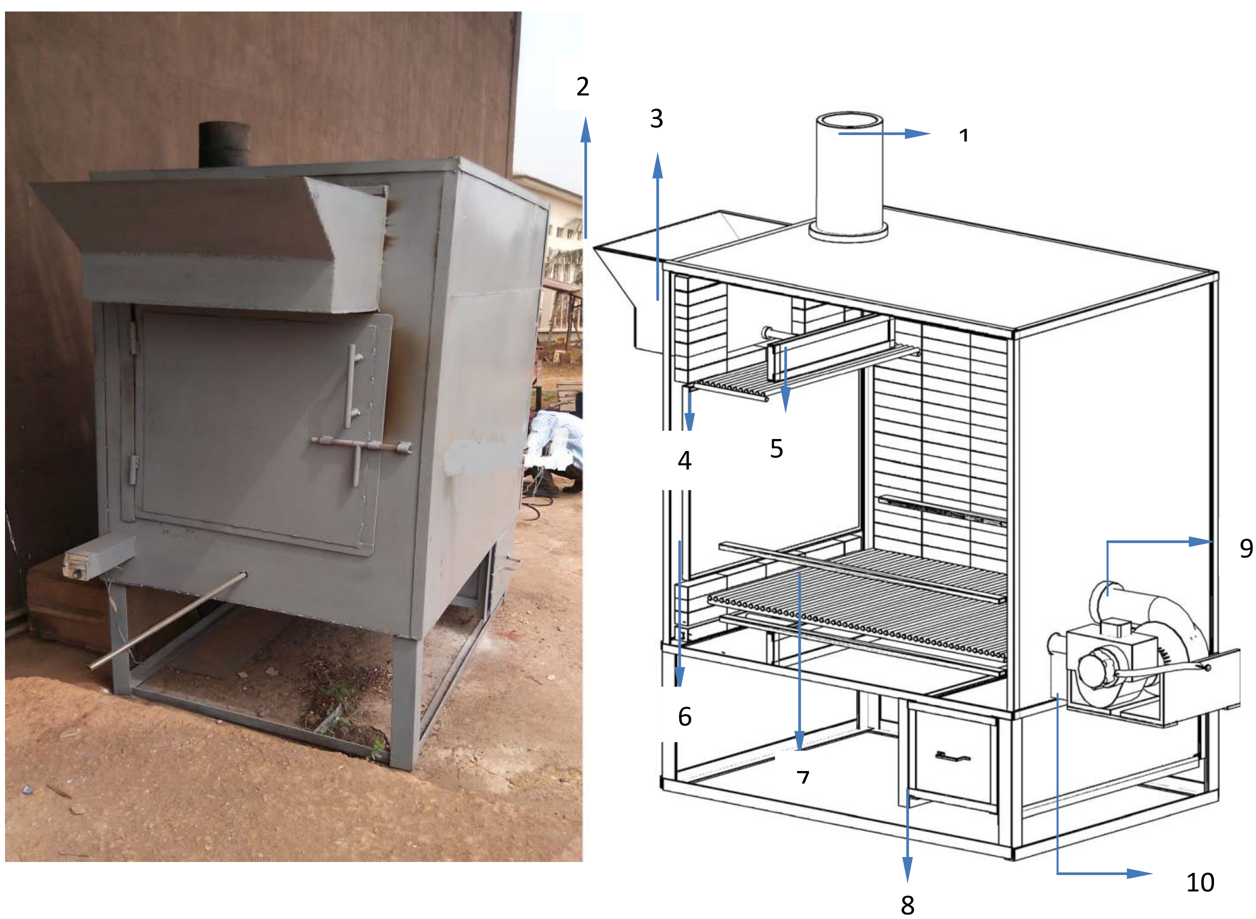

Figure 2 : The pictorial and isometric view of the incinerator

1. Chimney
2. Hopper
3. Refractory bricks
4. Drying grate
5. Feed ram
6. Combustion air piping
7. Combustion grate

8. Ash tray
9. Blower
10. Burner

Nomenclature

m	Mass, *kg*
C_p	Specific heat capacity, *kJ/kg°C*
T_g	Temperature of flue gas, °*C*
T_c	AmbientTemperature, °*C*
d_t	Temperaturedifference, °*C*
H_v	Latent heat of vapourization,*kJ/kg*
Q_o	Heat input, *kJ*
Q_1	exit heat, *kJ*
η	Combustion efficiency, %