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A REFUSE FIRE BOILER UTILIZING THE CONCEPT OF WASTE TO ENERGY

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Abstract: **In developing countries refuse (waste) management remains a major challenge due to a prevalent improper waste disposal practices. This study focuses on the design and fabrication of a refuse boiler that leverages the concept of waste-to-energy (WTE) to address both refuse disposal and energy production. The study explores the use of municipal solid waste (MSW) as a fuel source for the boiler, an approach that not only reduces waste volume but also contributes to energy production. The systematic approach to the design, fabrication, experimental procedure and testing of the developed refuse fire boiler followed a Steam pressure of 2 bar to 5 bar, Steam temperature of 120ºC to 180ºC, Steam capacity of 5kg/h to 20 kg/h, Stoichiometric air-fuel ratio and Calorific value of solid waste used as fuel. The determination of the calorific value of municipal waste was accomplished using a locally fabricated bomb calorimeter. Values of 12572.22KJ/Kg, 14012.05KJ/Kg, 21833.26KJ/Kg and 20551.01KJ/Kg of paper products, wood waste, plastics waste and textile waste were obtained respectively. The test of operational performance of the constructed boiler (Pilot boiler) was achieved by employing a pressure build up test in comparison with an already existing industrial boiler (Control boiler).**

Keywords: **Refuse-fired boiler, Waste-to-Energy (WTE), Municipal Solid Waste (MSW), Renewable Energy, Waste management, Boiler design, Environmental Energy recovery.**

I. INTRODUCTION

Waste management poses a major challenge worldwide, especially in developing countries such as Nigeria, where improper disposal of municipal solid waste (MSW) is a widespread problem. Common sources of MSW include residential, commercial, and industrial sites, with waste often being dumped near landfills, oceans, rivers, and lakes [1, 2]. The accumulation of waste not only creates environmental risks but also aggravates public health issues. For this reason, various methods such as recycling, composting, and incineration are used to manage waste, though each of these solutions have their own limitations to effectively address the growing problem. Incineration as one of these potential solutions, especially municipal waste incineration, has been practiced for over a century in developed regions such as Europe and the United States. However, integrating this process into steam generation systems for large-scale power generation is relatively new. Boilers, which are essential tools for this purpose, work by transferring heat from burning fuel to water, converting it into steam at the desired temperature and pressure. Boilers can be classified into fire tube type and water tube type, each with its own design and operating characteristics. In the case of waste boilers, integration of the incinerator with heat recovery equipment is necessary to produce energy from waste. This is a fast growing concept that is gaining ground in many developing countries as a sustainable solution for waste treatment [3, 4]. Waste-to-energy technologies, including mass incineration systems and waste-derived fuel (WDF), have been recognized for their environmental and socioeconomic benefits. These systems reduce CO_2 emissions compared to fossil fuels because they use renewable energy sources.

Additionally, by-products of incineration, such as fly ash and bottom ash, can be reused in industries such as fertilizer production and ceramic manufacturing, adding value beyond energy production [5].

The need for this research stems from the dual challenges of waste management and energy shortages. Nigeria, like many developing countries, faces an urgent need to find effective and environmentally friendly waste disposal methods, while also seeking alternative energy sources due to natural resources [6]. Moreover, fossil materials are decreasing day by day. The use of municipal solid waste as fuel in waste-to-energy (WTE) systems offers a promising solution, providing both waste management and energy production benefits. WTE technologies, including mass incineration and WDF incineration, differ in waste preparation before incineration, which affects the effectiveness and efficiency of the process. This research aimed to design and manufacture a waste boiler, capable of burning solid waste to recover energy in the form of steam, which can then be used to produce electricity. Research objectives include determining the calorific value of solid waste, evaluating the performance of the designed boiler and comparing it with existing systems. The expected outcome is a sustainable and efficient waste management solution that reduces environmental pollution and provides a renewable energy source. The study is justified through its contributes to the ongoing discussion on sustainable waste management and renewable energy solutions. Thus, in designing a waste boiler, the study addresses important issues of waste disposal and energy shortage, providing practical insights into the design, operational efficiency, and environmental benefits of such systems. This study is not only relevant for Nigeria but also has implications for other developing regions facing similar challenges.

II. LITERATURE REVIEW

This section gives an overview of the various previously undertaken studies by researchers in the field of boiler development.

Over the years, Boiler technology has advanced in no small measure, leading to the development of numerous models of boilers for different uses. Based on their categorization, boilers can be grouped into water tubes, fire tubes, packaged boilers, fluidised bed combustion (FBC) boilers, pulverised fuel boilers, and waste boilers. Each of these models have their unique properties and uses, and this is because of the varying needs of industrial and commercial heating. In a water tube boiler, the water flows through tubes that are surrounded by gas, which turns the water into steam. These boilers have capacities ranging from 4,500 to 120,000 kg/h, and are frequently employed in businesses that require steam and high pressure. They are appropriate for large-scale operations because of their design, which guarantees effective heat transmission and quick steam generation [7]. On the other hand, although they are not as widely used as water tube boiler, fire tube boilers are distinguished by the combustion gases that flow through tubes that have water surrounding them. With capacity up to 12,000 kg/h, these boilers generate steam at lower pressures and are commonly employed in applications needing medium steam pressures. Fire tube boilers are prized for their simplicity and convenience of use despite having smaller capacities and pressure ranges [8]. Another significant category of boilers is the packaged boilers, which are distinguished by their simple installation and small construction. These boilers, which are often shell-type units, come as a full kit with all the parts that are needed; all that is needed is a connection to the fuel, water, and electricity supplies. They are well known for their excellent thermal efficiency, are mostly run on petroleum, since the restricted combustion space improves heat transfer [8, 9]. Boilers that use fluidised bed combustion (FBC) technology are more sophisticated because they suspend fuel and sand bed through high-speed airflow, which produces extremely efficient combustion. At 850 to 950°C, a variety of fuels, including coal, wood, biomass, and even sludge, can be burned completely in their liquefied state. Also, since they function as oxygen carriers and produce CO_2 and H_2O with minimal energy loss, metal oxide particles like Fe_2O_3 can be used in the combustion layer to further increase combustion efficiency [10, 11]. Boilers with fluidised beds are categorised as atmospheric (AFBC), pressurised (PFBC), or circulating (CFBC), with each type having differing benefit for fuel and emissions management flexibility [12, 13]. Today, pulverised fuel boilers are widely utilised, and this is because of its capacity to burn finely ground coal, excellent combustion efficiency, and capacity for handling substantial fuel loads. When high and consistent energy production is needed, these boilers are crucial for power generating and large industrial sites. Furthermore, the purpose of wastewater boilers, often referred to as waste incineration boilers, is to burn municipal solid waste (MSW) and turn it into useful energy. This is important as it solves waste management problems and offers a substitute energy source, thus turning the technology to become more and more significant. Additionally, Habib et al. emphasised the novel technique of oxygen fuel combustion, which burns fuel with pure oxygen instead of air and produces exhaust gas primarily composed of CO_2 and water vapour. This technique is a viable way to lower greenhouse gas emissions

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from industrial processes since it not only speeds up heat transfer but also makes it easier to separate and absorb CO_2 [14]. For this body of research, the focus is to show how the boiler technology may be used to suit a wide range of industrial needs, from the production of high-pressure steam to the provision of ecologically appropriate waste treatment options. The continuous attempts to increase the efficiency and lessen the environmental impact of industrial heating operations are highlighted by advancements in boiler design and fuel usage, including the switch to renewable and alternative energy sources.

III. MACHINE DESIGN AND PERFORMANCE EVALUATION

A. Description of Refuse Fire Boiler and Working Principle

The rectangular shaped boiler is made up of an external casing constructed of mild steel. The boiler houses a water reservoir which is located above the fire pot. Directly below the water reservoir is a mild steel grate in which waste material is burnt. A door hatch serves as a cover for the entry into the fire pot. The fire pot bed is constructed with space gaps between a roll of rods to eased ash deposition. The waste is then feed into the combustion chamber through a chute situated on top of the boiler. The cold water inlet pipe runs from the top and is connected to a retainer or water reservoir situated within the combustion chamber.

Fig. 1. Pictorial View of the Fabricated Refuse Fired Boiler

B. Design Considerations

The systematic approach to the design, fabrication, experimental procedure and testing of the developed refuse fire boiler for energy generation are as follows:

i. Steam pressure of 2 bar to 5 bar

ii. Steam temperature of 120 ^oC to 180^oC

iii. Steam capacity of 5kg/h to 20 kg/h

iv. Stoichiometric air-fuel ratio

v. Calorific value of solid waste used as fuel

C. Design Theories and Calculations

The boiler is a vessel that operates under pressure; hence, the design theories are the basic principles considered for the evaluation various parameters, dimensions and the performance of the boiler under internal pressure.

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Table 1. Summary of the design calculation

Initial Data	Calculations	Results and Remarks
Type of boiler	Refuse boiler	
Internal design pressure of the boiler		
$\sigma_{ut} = 385$ MN/m^2 t =0.002 $R_i = 0.2M$ $f_s = 5$	$P_d = \frac{\sigma_u Xt}{R_i Xf_s} = \frac{385X0.002}{0.2X5}$ $P_d = 0.77$MN/m^2 $\cong 770{,}00N/m^2$ Hence, P_d = 7.7 bar	The design pressure is calculated as: P_d =7.7 bar
Stresses in the tubes and drum		
For the Drum $P_d = 7.7bar$ $t = 0.002m$ $D_i = 0.4m$	$\sigma_{t1} = \frac{p_{dXD_i}}{2t} = \frac{0.77X0.4}{2X0.002}$ $\sigma_{t2} = 77MN/m^2$ $\sigma_{t1} = \frac{p_{dXD_i}}{4t} = \frac{0.77X0.4}{4X0.002}$ $\sigma_{t2} = 38.5MN/m^2$	σ_{t2} = Circumferential or hoops stress (N/m^2) calculated as $\sigma_{t2} = 77MN/m^2$ σ_{t2} =Longitudinal stress (N/m^2). Calculated as $\sigma_{t2} = 38.5MN/m^2$
Design of steam drum		
$D_i = 0.4m$ $L_{dru} = 0.1m$	Volume of steam drum or boiler shell $\frac{\pi}{4}X0.4^2X1 = 0.1257m^3$	For this design specification, the volume of steam drum was calculated as V_{dru} = 0.283m^3
Design of steam tubes		
$D_i = 0.0127m$ $L_{st} = 2m$	Volume of tube $\frac{\pi}{4}X0.4^2X1 = 0.0002X2 = 0.038m^3$	Babcock & Wilcox, stated that the minimum and maximum allowable tube diameter are 0.01m and 0.0635m. therefore the volume of the steam tube was calculated as V_{dru} = 0.038m^3
Design of combustion chamber		
$D_i = 0.5m$ $H_{com} = 1m$	Volume of combustion chamber $V_{com}\frac{\pi}{4}X0.5^2X1 = 0.196m^3$	For this design specification, the volume of combustion chamber was calculated as V_{com} =0.196m^3
Design of minimum wall thickness		
For the Drum $p_d = 0.77MN/m^2$ $D_i = 0.6m$ $\eta_E = 1$ $\sigma_{t1} = 77MN/m^2$ $also, forthetube$ $d_i = 0.0127m$ $c = 3$	$t_w = \frac{p_d XR_i}{\sigma X\eta_E - 0.6P_d} = \frac{0.77x0.3}{77X1 - 0.6X0.77}$ $t_w = 3.0181X10^{-3}$ $t_w = 3.018mm$ $t_{wtubes} = \frac{p_d Xr_i}{2X\sigma X\eta_E + 0.8P_d} + c$ $t_{wtubes} = \frac{p_d Xr_i}{2X77X1 + 0.8X0.77} + 3$ $t_w tube = 3.0312mm$	$t_w = 3.018mm$ Take t_w = 3.0mm $t_w tube = 3.0312mm$ Take $t_w tube = 3.0mm$

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Velocity of fluids in tubes, pipes and drum		
From steam table; V = 0.3427m²/kg water at 155⁰c M_w =48(kg/hr)	$v = 0.05 X M_w X \frac{v}{D_i^2} = 0.05 X 48 X \frac{0.3427}{0.6^2}$ $V = 2.284 m/s$	For this design specification, the velocity of fluids in the steam drum is calculated to be V=2.284m/s
Quantity flow rate of fluid inside tubes		
V =2.284m/s d_i =0.0127	$Q_d = \frac{\pi}{4} d_i^2 X v = \frac{\pi}{4} X 0.0127^2 X 2.284$ $Q_d = 2.8933 X 10^{-4} m^3/h$	$Q_d = 0.000289 m^3/h$ $Q_d = 4.817 X 10^{-6} m^3/\min$
Design of frame support		
L = 0.6m B = 0.3m H = 1.5m	Area of frame support 0.6 x 0.3 x 1.5 = 0.270m	Area = 0.270m

D. Boiler Performance Evaluation

Safe and effective operation of a boiler needs the right amount of pressure. when the right pressure is not attained the boiler, the ability to perform properly is limited. The operational effectiveness of the design refused fired boiler was evaluated employing a pressure build-up test. This test was carried out incorporating a control boiler (pre-existing boiler) and the pilot boiler that has been fabricated. The test data were obtained at predetermined time intervals of 5mins, 3mins and 2mins respectively. The pressure build-up test procedure for the control boiler is detailed below;

(i) Water reservoir is filled with water of about 7litres through a feed water inlet at the top of the boiler.

(ii) The firepot is filled with a homogenous mixed of solid waste

(iii) Solid is pre-ignited using kerosene, petrol or liquid natural gas

(iv) After pre-ignition has taken place, the refuse waste burns within the combustion chamber aided with a supply of air provided by electric motor pump.

(v) The heat generated from the burn refuse is transferred by means radiation and conduction to the water in the reservoir. pressure developed in the boiler as indicated by a pressure gauge is noted at pre-defined time intervals.

(vi) The temperature probe gives an indication of the water temperature at above 100⁰C, when steam is generated.

(vii) As the steam generated passes the steam outlet, the steam valve is closed.

The data obtained during the pressure build-up test are outline in Tables 2, 3 and 4 at time intervals of 5min, 3mins and 2mins respectively.

Table 2. Pilot boiler and control boiler with pressure boiled up rate at 5mins Interval

Time (min)	Pilot boiler pressure (psi)	Control boiler pressure (psi)
0	0	0
5	0	0
10	0	3.75
15	7.5	7.50
20	30	11.25
25	39	15
30	42	24
35	45	30

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Table 3. Pilot Boiler and Control Boiler with Pressure Build-up rate at 3mins interval

Time (min)	Pilot boiler pressure (psi)	Control boiler pressure (psi)
0	0	0
3	1.5	0
6	11.25	15
9	21	18
12	30	18
15	37.75	24
18	42.75	27
21	45	30

Table 4. Pilot and Control Boiler with Pressure Build-up rate at 2mins interval

Time (minutes)	Pilot boiler pressure psi	Control boiler pressure (psi)
0	0	0
2	3	15
4	15	18
6	18	18
8	22.5	24
10	24	27
12	30	30

E. Student's T-test Analysis

The student's t-test was adopted for the analysis of the pressure build up data obtained from the control and pilot boiler.

The Student's *t*-test is a statistical test that compares the mean and standard deviation of two samples to see if there is a significant difference between them. In this study a t-test is used to calculate whether or not differences seen between the control and pilot boiler pressure are a factor of the manipulated variable or simply the result of chance. In any significance test, there are two possible hypotheses:

Null Hypothesis: There is not a significant difference between the two groups; any observed differences may be due to chance and sampling error.

Alternative Hypothesis: There is a significant difference between the two groups; the observed differences are most likely not due to chance or sampling error.

- In this study t-test was specified to be two tailed test which simply specifies whether the two populations are different from one another.

In this scenario test statistic t is then calculated. If the value of t-statistics calculated is greater than the critical value determined by the appropriate reference distribution, the null hypotheses is rejected.

Table 5. Data developed for student's t distribution from Table 2.

Time (min)	y (psi)	x (psi)	y-ȳ	$(y-\bar{y})^2$	$(x-\bar{x})$	$(x-\bar{x})^2$
0	0	0	-20.435	417.712	-11.438	130.828
5	0	0	-20.435	417.712	-11.438	130.828
10	0	3.75	-20.435	417.712	-7.688	59.105
15	7.5	7.5	-12.938	167.392	-3.938	15.105
20	30	11.25	9.562	91.432	-0.188	0.0353
25	39	15	18.562	344.548	3.562	12.688
30	42	24	21.562	464.919	12.562	157.804
35	45	30	24.438	597.216	18.562	344.548
	$\sum y = 163.5$	$\sum x = 91.5$		$\sum (y-\bar{y})^2 =$ 2918.643		$\sum (x-\bar{x})^2 =$ 851.344 $d.f = n-1 = 7$

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y = Pilot boiler pressure

x = Control boiler pressure

ȳ = Pilot boiler sample mean

$\bar{x}$ = control boiler sample mean

Let n be sample size and (n – 1) degree of freedom

Hypotheses:

Ho: the mean pressures are the same

Ha: the mean pressures are different

S_y = pilot boiler standard deviation

Sample mean, $\bar{y} = \frac{\sum_{i=1}^{n} y^i}{n} = \frac{163.5}{8} = 20.438\, psi$

Sample mean, $\bar{x} = \frac{\sum_{i=1}^{n} x^i}{n} = \frac{91.5}{8} = 11.438\, psi$

Standard deviation $S_Y = \sqrt{\sum \frac{(Y-\bar{Y})^2}{n-1}}$ (1)

$= \sqrt{\frac{2918.643}{7}} = 20.419$

Test statistic: $t = \frac{\bar{y}-\mu_O}{S_y/\sqrt{n}} = \frac{20.438-11.438}{20.419/\sqrt{8}} = 1.247$ (2)

Where $\mu_o = mean\ \bar{x}$

For a two sided test at a common level of significance α =0.05, the critical values from t-distribution tables on 7degree of freedom are -2.365 and 2.365. The calculated t does not exceed these values hence the null hypotheses cannot be rejected with 95% confidence.

To compute sample confidence interval for μ, we determine: estimated standard deviation of,

$\bar{y} = \frac{S}{\sqrt{n}} = \frac{20.419}{\sqrt{8}} = 7.219$ (3)

$\alpha = 0.05, t_{\alpha.2} = 2.365$

95% confidence interval for μ_o is ȳ- $t_{\alpha.2}\ {}^{Sy}/\sqrt{n} < \mu <$ ȳ + $t_{\alpha.2}\ {}^{Sy}/\sqrt{n}$

= 20.438 -2.365 (7.219) < μ < 20.438 + 2.365 (7.219) = 3.364 < μ < 37.493

Table 6. Data developed for student's t distribution from Table 3.

Time (min)	y (psi)	x (psi)	y-ȳ	(y- ȳ)^2	(x- $\bar{x}$)	(x- $\bar{x}$)^2
0	0	0	-23.625	558.141	-16.5	272.25
3	1.5	0	-22.125	489.516	-16.5	272.25
6	11.25	10	- 12.375	153.141	-1.5	2.25
9	21	12	-2.625	6.891	1.5	2.25
12	30	12	6.375	40.641	1.5	2.25
15	37.5	16	13.875	192.516	7.5	56.25

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18	42.75	18	19.125	365.766	10.5	110.25
21	45	20	21.375	456.891	13.5	182.25
	$\sum y = 189$	$\sum x = 132$		$\sum (y-\bar{y})^2 =$ 2263.503		$\sum (x-\bar{x})^2 =$ 900 $d.f = n-1 = 7$

Hypotheses:

H_0: The mean pressures are the same

H_a: The mean pressures are different

Sample mean, $\bar{y} = \dfrac{\sum_{i=1}^{n} y^i}{n} = \dfrac{189}{8} = 23.625\, psi$

Sample mean, $\bar{x} = \dfrac{\sum_{i=1}^{n} x^i}{n} = \dfrac{132}{8} = 16.5\, psi$

Standard deviation $S_Y = \sqrt{\sum \frac{(Y-\bar{Y})^2}{n-1}}$

$= \sqrt{\dfrac{2263.503}{7}} = 17.982$

Test statistic (t calculated) $t = \frac{\bar{y}-\mu_o}{S_y/\sqrt{n}}$

$$= \frac{23.625 - 16.5}{17.982/\sqrt{8}} = 1.121$$

To compute sample confidence interval for μ_o we determine: estimated standard deviation of $\bar{y} = {}^{Sy}\!\sqrt{n} = \dfrac{17.982}{\sqrt{8}} = 6.358$

For;

$\alpha = 0.05, t_{\alpha.2} = 2.365$

95% confidence interval for μ_o is ȳ - $t_{\alpha.2}\, {}^{Sy}\!/\!\sqrt{n} < \mu <$ ȳ + $t_{\alpha.2}\, {}^{Sy}\!/\!\sqrt{n}$

= 23.625 - 2.365 (6.358) <μ_o< 23.625 + 2.365 (6.358) = 8.588 <μ_o< 38.662

Table 7. Data developed for student's t distribution from Table 4.

Time (min)	y (psi)	x (psi)	y-ȳ	(y- ȳ)^2	(x- $\bar{x}$)	(x- $\bar{x}$)^2
0	0	0	-16.071	258.277	-18.857	335.586
2	3	15	-13.071	170.851	-3.857	14.877
4	15	18	-1.071	1.147	-0.857	0.735
6	18	18	1.929	3.721	-0.857	0.735
8	22.5	24	6.429	41.332	5.143	26.451
10	24	27	7.929	62.869	8.143	66.309
12	30	30	13.929	194.017	11.143	124.167
	$\sum y = 112.5$	$\sum x = 132$		$\sum (y-\bar{y})^2 =$ 732.214		$\sum (x-\bar{x})^2 =$ 588.125 $d.f = n-1 = 6$

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Hypotheses:

H_0: The mean pressures are the same

H_a: The mean pressures are different

Sample mean, $\bar{y} = \frac{\sum_{i=1}^{n} y^i}{n} = \frac{112.5}{7} = 16.071\, psi$

Sample mean, $\bar{x} = \frac{\sum_{i=1}^{n} x^i}{n} = \frac{132}{7} = 18.875\, psi$

Standard deviation $S_Y = \sqrt{\sum \frac{(Y-\bar{Y})^2}{n-1}}$

$= \sqrt{\frac{732.214}{6}} = 11.047$

Test statistic (t calculated) $t = \frac{\bar{y}-\mu_o}{S_y/\sqrt{n}}$

$= \frac{16.071 - 18.875}{7.362/\sqrt{7}} = -0.667$

To compute sample confidence interval forμ_o, we determine: estimated standard deviation of

$\bar{y} = {}^{Sy}/\sqrt{n} = \frac{11.047}{\sqrt{7}} = 4.175$

For;

$\alpha = 0.05, t_{\alpha.2} = 2.447$

95% confidence interval for μ_o is ȳ - $t_{\alpha.2}\ {}^{Sy}/\sqrt{n} < \mu <$ ȳ + $t_{\alpha.2}\ {}^{Sy}/\sqrt{n}$

= 16.071 - 2.447 (4.175) <μ_o< 16.071 + 2.447 (4.175) = 5.854 <μ_o< 26.287

F. Calculation of Calorific value of MSW

The first step in the processing of a waste is to determine its calorific content or heating value. This is a measure of the temperature and the oxygen requirements that the specific waste will be placed on the system. The calorific value of a fuel can be determined either from their chemical analysis or in the laboratory. In the laboratory Bomb Calorimeter is used. The analysis some sample of wastes using Bomb Calorimeter locally fabricated as shown in Fig. 2 in Table 8.

Combustible part of the MSW was used for the experiment. A sample of 100 g was taken from combustibles after separating non combustibles. They were kept in oven for 24 hrs under 105ºC for calculating the moisture contents. The dried samples were size reduced using a blender and separated using a 1 mm sieve for achieving complete combustion in the Bomb Calorimeter tests. Two replicates of each type of waste (food waste, textile, plastic and paper) were tested to obtain the calorific values in the apparatus. The samples were burnt in pure oxygen in an enclosed volume and the energy given off was measured as the temperature increase of the bomb and its surroundings.

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Fig. 2. View of the Local Fabricated Bomb Calorimeter

Table 8. Calculation of Calorific value of the fuel using Bomb Calorimeter

Paper product	**Wood waste**	**Plastics waste**	**Textile waste**
Sample wt.m,=1.060g	Sample wt.m,=0.974g	Sample wt.m,=1.023g	Sample wt.,m,=1.065g
Initial Temp. = 29.986° *C* Final Temp. = 31.009°C ΔT =1.023°C. _	Initial Temp. =29.933°C Final Temp.=30.981° *C* ΔT = 1.048°C	Initial Temp. =28.743°C Final Temp.= 30.457° C ΔT = 1.714°C	Initial Temp. =29.015°C Final Temp. = 30.695° C ΔT =1.68°C .
Unburnt = 2.5+3.0=5.5	Unburnt = 1.3+2.2=3.5	Unburnt = 1.6+2.7=4.3	Unburnt = 2.5+0.8=3.3
Burnt = 10 - 5.5 = 4.5	Burnt = 10 - 3.5 = 6.5	Burnt = 10 - 4.3 = 5.7	Burnt = 10 - 3.3 = 6.7
Φ = 4.5*2.3 =10.35	Φ = 6.5*2.3 =14.95	Φ = 5.7*2.3 =13.11	Φ = 6.7 * 2.3 = 15.41
V =2.3	*V* = 2.5	*V* = 3.9	*V* = 3.8
E =13039.308	*E =13039.308*	*E =13039.308*	*E =13039.308*
$CV_p = (EAT - \Phi - V)/m$.	$CV_w = (EAT - \Phi - V)/m$	$CV_p = (EAT - \Phi - V)/m$	$CV_p = (EAT - \Phi - V)/m$
CV_P *=12572.22J/g*	CV_w =1401205J/g	CV_P *=21833.26J* / g	CV_P = 20551.01J/g
=12572.22KJ/kg	= 14012.05KJ/kg	= 21833.26KJ/kg	=20551.01KJ/kg

For chemical analysis, using Dulong's formula, percentage by mass was considered and heat of combustion of Carbon, Oxygen and Hydrogen.

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IV. RESULT AND DISCUSSION

A. Results of Boiler Performance

The T Distribution (and the associated t scores), are used in hypothesis testing to figure out the acceptance or rejection of the null hypothesis. The results obtained from the analysis of data on Table 5 through 7 and the testing of hypotheses were as follows:

(i) Reject H_O when $t_{cal} > t_{table}$ or $t_{cal} < -t_{table}$

(ii) Accept h_o when $t_{cal} < t_{table}$ or $t_{cal} > -t_{table}$

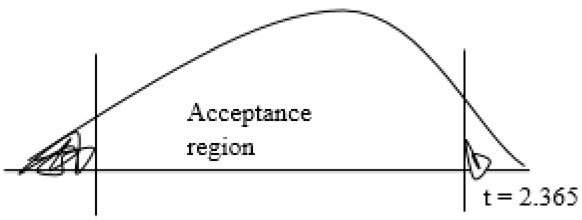
Results of Table 5.

The central region on this graph is the acceptance area and the tail is the rejection region, or regions. In this particular graph of a two tailed test, the rejection region is shaded. The area in the tail can be described with z-scores or t-scores.

$t_{cal} = 1.246$

$t_{table} = 2.365$

Since $t_{cal} > t_{tablel}$ we have no evidence to reject the null hypothesis. The meaning of this statistical inference is that the pressure characteristics for the pilot and industrial boilers are statistically similar.



95% confidence interval for μ give $3.364 < \mu < 37.493$

This implies that the mean pressure of the pilot boiler lies between 3.364 psi and 37.493 psi

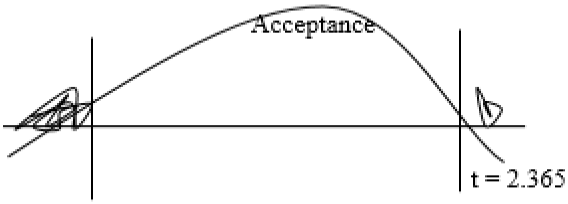
Results of Table 6.

$t_{cal} = 1..121$

$t_{cal} = 2.365$

Since $t_{cal} < t_{tablel}$ we accept the null hypothesis and conclude that the mean pressures are similar.

Acceptance



95% confidence interval for μ is $8.588 < \mu < 38.662$.

This reveals that mean pressure of the pilot boiler falls within the range of 8.588psi to 38.662 psi for the given time interval and there is no need to reject the null hypotheses.

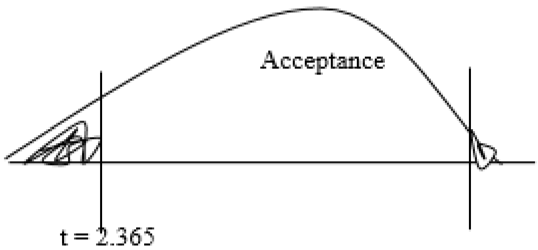
Results of Table 7.

$t_{cal} = -0.668$

t_{table} =2.447

Since $t_{cal} > t_{tablel}$ we conclude that their exists similarity in the pressure characteristics of the pilot and industrial boilers. Further meaning is that if the pilot boiler is scaled up, it will have exactly the same performance with the existing industrial boiler studied,

Acceptance



95% confidence interval obtained for μ is 5.854 < μ < 26.2387.

This indicates that we need to increase the sample size in order to obtain more accurate estimate. In short, when the mean y = 16.071 psi as an estimate of the true average pressure of the pilot boiler we can be 95% confident that the error of this estimate is at most 11.047 psi.

V. CONCLUSION

As the national economy experiences rapid growth, leading to an increase in the level of rural urban drift, along with improvement of the living standards of the populace, the amount of municipal solid waste generated has increased greatly. This has led to the pollution of the environment, with its attendant effect on people's health, which invariably is a source of public concern in the larger society. The challenge of proper management and treatment of waste requires urgent attention for sustainable development of cities. In this study, the fabrication of a refuse boiler has been successfully done using local mild steel and galvanized steel with the use criterion of heat resistance and corrosion resistance. The determination of the calorific value of municipal waste has been accomplished using a locally fabricated bomb calorimeter. Values of 12572.22KJ/Kg, 14012.05KJ/Kg, 21833.26KJ/Kg and 20551.01KJ/Kg of paper product, wood waste, plastics waste and textile waste were obtained respectively. The test of operational performance of the constructed boiler (Pilot boiler) was achieved employing a pressure build up test in comparison with an already existing industrial boiler (Control boiler). The Student’s t-test results of the pressure build up data at 5% level of significance revealed no significant difference in the mean of the pressures of pilot and control boiler at given time interval of 5mins, 3mins and 2mins respectively. This more or less means that if pilot boiler is scale-up, it’s possible to attain the same performance as the existing industrial boiler. The 95% confidence interval estimate gave a range pilot pressures of about the mean pressures at the pre-defined time intervals. The lowest and highest pressures about the mean pressures were (3.364psi, 38.662psi). This is an indication of average attainable working pressure of the boiler.

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