Flue Gas Analysis of a Small-Scale Municipal Solid Waste-Fired Steam Generator

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Abstract

Flue gas analysis of a small-scale municipal solid waste-fired steam generator has been presented in this work. The analysis was based on the selected design parameters: operating steam pressure of 10 bar, with fuel consumption rate of 500 Kg/h and combustion chamber which utilizes mass burn incineration using water wall furnace. The plant is designed as a possible option for thermal utilization of rural and urban wastes in Nigeria. The average daily generation of MSW was considered in order to assess the availability of the material. The data were collected from Enugu State Waste Management Authority (ENSWAMA).This was calculated based on the state population, urbanization and industrialization strengths. Calculation of calorific value of the waste to determine the heat contents was carried out using two methods: Bomb calorimeter and Dulong's formula. Some samples of the garbage were analyzed with bomb calorimeter in the National Centre For Energy Research & Development Laboratory, University of Nigeria Nsukka. This is important because it a direct measure of the temperature requirements that the specific waste will place on the system. The calorific values obtained from this analysis were 12572.308 KJ/kg, 14012.05 KJ/kg, 21833.26 KJ/kg and 20551.01 KJ/kg for paper products, woods, plastics and textiles waste respectively, while the energy content obtained from the elemental composition of waste using Dulong's formula was 15,101 KJ/kg .The maximum temperature of the furnace attained from the energy balance based on this value around the combustion chamber was 833.7 K and the amount of air required per kg of MSW was 8.66kg

Keywords: Solid-Waste, Steam, Temperature, Pressure, Flue gas, Calorific Value, Excess air, Moisture Content, Exergy, Energy, Combustion.

1. Introduction

As a result of high carbon dioxide, CO_2 emission from thermal energy conversion of fossil fuels which is one of the major causes of the greenhouse effect, boiler technologies based on biomass conversion represent a great potential to reduce CO_2 emission since they are based on the utilization of renewal energy source.Furthermore, since conventional energy sources are finite and fast depleting and energy demand is on the increase, it is necessary for scientists and engineers to explore alternative energy sources, such as municipal solid waste (MSW).Biomass is abundantly available on the earth in the form of agricultural residues, city garbage, cattle dung, but is normally underutilized. For an efficient utilization of these resources, adequate design of municipal solid waste- fired steam boiler is necessary in order to extract heat produced in the combustion of waste, considering the calculated high calorific value of MSW and the availability of this material around us. The environmental benefits of biomass technologies are among its greatest assets. Global warming is gaining greater acceptance in the scientific community. There appears now to be a consensus among the world's leading environmental scientists and informed individuals in the energy and environmental communities that there is a discernable human influence on the climate; and that there is a link between the concentration of carbon dioxide (one of the greenhouse gases) and the increase in global temperatures.

Appropriate utilization of Municipal Solid Waste when used can play an essential role in reducing greenhouse gases, thus reducing the impact on the atmosphere. In addition, some of the fine particles emitted from MSW are beneficial. Bottom and fly ash are being mixed with sludge from brewery's wastewater effluent treatment in a composting process, thus resulting in the production of a solid fertilizer. The possibility of selling the bottom and fly ash to the ceramics industry is also being considered, which increases the potentials of MSW fired steam boiler. S.O. Adefemi et al[1] in their work on this subject correlated the concentration of heavy metals in roots of plant from Igbaletere (in Nigeria) dump site with the concentration of heavy metals in the soil samples from the dump site. A. B. Nabegu [2] found out that solid waste generated by households (62.5%) in Kano metropolis far out weighed that generated by various institutions in the same metropolis (5.8%). In the analysis of Municipal Solid Waste management in Addis Ababa, Nigatu et al[3] observed that part of the reasons for low performance solid waste management was the inadequate and malfunctioning of operation equipment and open burning of garbage. This study thus seeks to analyse an efficient operating and burning system.

2. Combustion Analysis Of Municipal Solid Waste (MSW)

Considering the theoretical combustion reaction for the organic component of the waste, such as carbon, hydrogen and sulphur, Coskun et al [4] gave the equation for stoichiometric combustion as :

$C + (O_2 + \frac{79}{21}N_2) \rightarrow CO_2 + \frac{79}{21}N_2$ (1)

$H + 0.25(O_2 + 3.76N_2) \rightarrow 0.5H_2O + 0.94N_2$ (2)

$S + (O_2 + 3.76N_2) \rightarrow SO_2 + 3.76N_2$ (3)

It is known that nitrogen reacts with oxygen over about 1200^0C to form NO_x. In calculations, the upper limit of the flue gas temperature is assumed as 1200^0 C. Combustion process is assumed as in ideal case (Stiochiometric). So, nitrogen is not considered to react with oxygen during combustion reaction. It limits the intimacy between the fuel molecules and O_2 [4]

Table 1 shows the average daily generation of municipal solid waste in various states of Nigeria.

Table 1 Average daily generation of MSW in Nigeria

S/N	State	Metric Tonne	S/N	State	Metric Tonne	S/N	State	Metric Tonne
1	Abia	11	14	Enugu	8	27	Ogun	9
2	Adamawa	8	15	Gombe	6	28	Ondo	9
3	Anambra	11	16	Imo	10	29	Osun	7
4	Akwa-Ibom	7	17	Jigawa	9	30	Oyo	12
5	Balyesa	8	18	Kaduna	15	31	Plateau	9
6	Bauchi	9	19	Kano	24	32	Rivers	15
7	Benue	8	20	Kastina	11	33	Sokoto	9
8	Borno	8	21	Kebbi	7	34	Taraba	6
9	Cross River	9	22	Kogi	7	35	Yobe	6
10	Delta	12	23	Kwara	7	36	Zamfara	6
11	Ebonyi	7	24	Lagos	30	37	FCT	11
12	Edo	8	25	Nasarawa	6			
13	Ekiti	7	26	Niger	10			

(Source: ENSWAMA, MOE and NPC)

Complete combustion by using excess air can be expressed as follows:

$C + (I + \lambda)(O_2 + 3.76CO_2) \rightarrow CO_2 + (I + \lambda)(3.76N_2) + \lambda O_2$ (4)

$H + (I + \lambda)(O_2 + 3.76N_2) \rightarrow 0.5H_2O + (I + \lambda)(3.76 N_2) + (0.75 + \lambda)O_2$ (5)

$S + (I + \lambda)(O_2 + 3.76N_2) \rightarrow SO_2 + (I + \lambda)(3.76N_2) + \lambda O_2$ (6)

In combustion reaction, λ is the fraction of excess combustion air, having the relationship, $n = (1+\lambda)$

where n is the excess air ratio and $\lambda = \frac{Actual \frac{A}{F} ratio - Stoichiometric \frac{A}{F} ratio}{Stoichiometric \frac{A}{F} ratio}$

The mass balance equation can be expressed as showed in figure 1 in the form as,

$m_{in} = m_{out}$ (7)

i.e. The mass of reactants is equal to the mass of products

$m_{fuel} + m_{air} = m_{flue\ gas} + m_{ash} + m_{mst}$ (8)

$m_{fluegas} = m_{air} + (m_{fuel} - m_{ash} - m_{mst})$ (9)

From Eqn. 8

$m_{air} = (m_{fluegas} + m_{ash} + m_{mst}) - m_{fuel}$ (10)

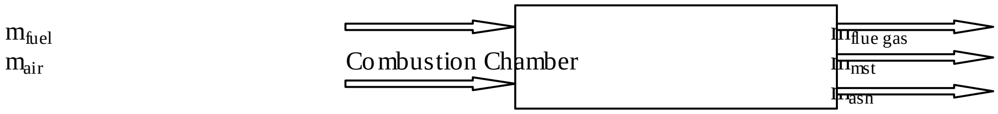

Fig.1 Mass balance in the Furnace

Stiochiometric air amount (n=1) can be calculated as follows;
$m_{air\ steo}$ = O_2 required per kilogram of the fuel/23.3% of O_2 in air
$= m_{O,H}K_H - m_{O,O}K_O + m_{O,S}K_S + m_{O,C}K_C/0.233$ (11)
Where $m_{O,H}$, $m_{O,O}$, $m_{O,S}$, $m_{O,C}$, are the masses of oxygen in hydrogen,oxygen,sulphur and carbon respectively.

$$m_{air,steo} = \frac{8K_H - K_O + K_S + \frac{32}{12}K_C}{0.233} \quad (12)$$

$$m_{air.Steo.} = 34.3348K_H - 4.2918K_O + 4.2918K_S + 11.4449K_C$$

$$m_{air.steo.} = (3K_H - 0.3750K_O + 0.3750K_S + K_C)11.4449 \quad (13)$$

With excess air ratio,

$$m_{air} = (3K_H - 0.3750K_O + 0.3750K_S + K_C)(11.4449)(1+\lambda) \quad (14)$$

Where K denotes the percentage ratio of the element in chemical composition (in %) and m_{air} is the air requirement per kg fuel (kg air/kg fuel). Flue gas amount can be found by Eq. 9
Substituting Eq.13 in Eq. 9, knowing that calculations are done for 1 kg fuel, so the equation can be expressed as follows:

$$m_{fluegas} = (3K_H - 0.3750K_O + 0.3750K_S + K_C)(11.4449) + (1-K_{ash}-K_{mst}) \quad (15)$$

Employing the excess air ratio,

$$m_{fluegas} = (3K_H - 0.3750K_O + 0.3750K_S + K_C)(11.4449)(1+\lambda) + (1 - K_{ash} - K_{mst}) \quad (16)$$

Using the elemental composition of waste as shown in figure 1, the calculation of amount of air required and the flue gas produced can be done considering the above equations.

Table 2 Percentage by mass of MSW

Element	C	H	O	S	N	Moisture	Ash
percentage	35.5	5.1	23.9	0.5	2.4	25	7.6

(Source : P.Chattopadhyay, 2006)

2.1 Calculation of Combustion air supply

Considering theoretical combustion reaction for the elemental analysis of MSW showed in table 2.

Carbon (C):
$C + O_2 \rightarrow CO_2$
$12Kg\ C + 32Kg\ O_2 \rightarrow 44Kg\ CO_2$
Oxygen required = 0.355 * (32/12) = 0.947/Kg MSW
Carbon dioxide produced = 0.355 * (44/12) = 1.302/Kg MSW
Hydrogen (H):
$H_2 + \frac{1}{2} O_2 \rightarrow H_2O$
$2Kg\ H_2 + 16Kg\ O_2 \rightarrow 18Kg\ H_2O$
$1Kg\ H_2 + 8Kg\ O_2 \rightarrow 9Kg\ H_2O$
Oxygen required = 0.051×8 = 0.408 Kg/Kg MSW
Steam produced = 0.051×9 = 0.459 Kg/Kg MSW
Sulphur (S):
$S + O_2 \rightarrow SO_2$

32Kg S + 32KgO_2 → 64KgSO_2
1KgS + 1KgO_2 → 2KgSO_2
Oxygen required = 0.005 Kg/Kg MSW
Sulphur dioxide produced = 2 × 0.005 = 0.01Kg/KgMSW

Table 3 Oxygen Required per Kilogram of MSW

Constituent	Mass fraction	Oxygen required (Kg/Kg MSW)
Carbon (C)	0.355	0.947
Hydrogen (H)	0.051	0.408
Sulphur (S)	0.005	0.005
Oxygen (O)	0.239	- 0.239
Nitrogen (N)	0.024	___
Moisture	0.25	___
Ash	0.190	___
		1.121

O_2 required per Kilogram of MSW = 1.121Kg

Air required per Kilogram of MSW $= \frac{1.121}{0.233} = 4.811$Kg

Where air is assumed to contain 23.3% O_2 by mass
I.e. Stiochiometric air/fuel ratio = 4.811:1
For air supply which is 80% in excess (this has been derived from industry experience according to (Chattopadhyay, 2006) which suggests that 80% of excess air is just enough to optimize the combustion of solid refuse in the mass-burning system.

Actual A/F ratio, $m_{air} = 4.811 + \left(\frac{80}{100} \times 4.811\right) = 8.660/1$

Or alternatively, m_{air} can be found using Eq. (3.14)

2.2 Flue gas analysis

N_2 supplied = 0.767 × 8.660= 6.642Kg
O_2 supplied = 0.233 × 8.660= 2.012Kg
In the product,
N_2 = 6.642 + 0.024= 6.666Kg and excess
O_2 = 2.012-1.121= 0.891Kg
The results are tabulated in Table 4

Table 4 Flue Gas Analysis (Volumetric flue gas analysis).

Product	m_i Kg/Kg MSW	$\frac{m_i}{\sum m_i} \times 100\%$	$\bar{m}_i$ Kg/Kmol	$n_i = \frac{m_i}{\bar{m}_i}$	Wet $n_i / \sum n_i$ %	Dry $n_i / \sum n_i$ %
CO_2	1.302	13.958	44	0.030	9.317	10.135
H_2O	0.459	4.921	18	0.026	8.075	___
SO_2	0.01	0.107	64	0.0002	0.062	0.068
O_2	0.891	9.552	32	0.028	8.696	9.459
N_2	6.666	71.462	28	0.238	73.913	80.405
Total	9.328	100		0.322wet	100	100
				0.296dry		

2.3. Calculation of flue gas specific heat capacity

The specific heat values of gases found in flue gas are required to be known in order to obtain the average specific heat capacity (C_p) of flue gas. Taking these values from thermodynamic tables, a model is formed. The reference combustion reaction is required to generate one formulation in energy balance. Since carbon is an element found almost in all fossil fuels, the combustion reaction is considered to be a reference reaction for the model. Then, the specific heat values of all gases are defined depending on carbon dioxide. For that purpose, model coefficients are defined and expressed in detail as follows (Coskun et al., 2009).

$$C_{p,\,fluegas} = \frac{C_{p,C}}{(a_C + b_N + c_H + d_S)} \times \frac{m_{tot.steo.}}{m_{fluegas}} + fA \qquad (17)$$

a, b, c, d and f are the model coefficients in Eq. (3.17). $C_{p,\text{flue gas}}$ represents the average flue gas specific heat value. $C_{p,C}$ is the specific heat of CO_2.

2.3.1 Estimation of coefficient 'a_c'

Calculation method of a_c is given by the following equation:

$$a_c = \frac{a_m}{a_{cp}} \qquad (18)$$

where, a_{cp} can be defined as the specific heat ratio of CO_2 to CO_2. So,
a_{cp} equals to 1. a_m can be indicated as the mass ratio of CO_2 to flue gas for n =1.

$$a_m = \frac{m_c}{m_{tot\cdot steo}} = \frac{3.667K_C}{m_{tot.steo.}} \qquad (19)$$

2.3.2 Estimation of coefficient 'b_N'

From (Coskun et al., 2009), calculation method of b_N is given by the following equation:

$$b_N = \frac{b_m}{b_{cp}} \qquad (.20)$$

where, b_{cp} can be defined as the specific heat ratio of CO_2 to N_2 for different temperatures. Coefficient b_{cp} is estimated by using heat capacity model. b_m can be defined as the mass ratio of N_2 to total flue gas.

$$b_{cp} = 0.9094 + 1.69 \times 10^{-4} \times T - \frac{11135}{T^2}$$

$$b_m = \frac{m_N}{m_{tot.steo.}}$$

$$b_m = \frac{0.767(2.9978.K_H - 0.3747 \times K_O + 0.3747 \times K_S \times K_C) \times (11.445) + K_N}{m_{tot.steo.}} \qquad (.21)$$

2.3.3 Estimation of coefficient 'c_H'

Coefficient 'c_H' can be expressed as in the following equation:

$$c_H = \frac{c_m}{c_{cp}} \qquad (22)$$

$$c_{cp} = 0.5657 - 6.68 \times 10^{-6} \times T - \frac{10465}{T^2} \qquad (23)$$

$$c_m = \frac{m_H}{m_{tot.steo.}} = \frac{8.938 \times K_H + K_M}{m_{tot.steo.}} \qquad (24)$$

2.3.4 Estimation of coefficient 'd_S'

Coefficient d_S can be expressed as in the following equation:

$$d_s = \frac{d_m}{d_{cp}} \tag{25}$$

where, d_{cp} can be defined as the specific heat ratio of CO_2 to SO_2 for different temperatures. Coefficient d_{Cp} is estimated by using Vapour Pressure Model. d_m can be defined as the mass ratio of SO_2 to total flue gas [4]

$$d_{cp} = e^{[2.679 - \frac{151.16}{T} - 0.289\ln(T)]} \tag{26}$$

$$d_m = \frac{m_s}{m_{tot.steo.}} = \frac{2 \times K_S}{m_{tot.steo.}} \tag{27}$$

2.3.5 Calculation of coefficient 'f_A'

Coefficient f_A is calculated for access air amount. Coefficient $_{fA}$ can be expressed as in the following equation

$$f_A = f_m.C_{P,A} \tag{28}$$

$$C_{P,A} = 0.7124 \times 1.0000 \times 11^T \times T^{0.051} \tag{29}$$

$$f_m = \frac{m_{air}.steo.(n-1)}{m_{fluegas}} \tag{30}$$

2.3.6 Calculation of $C_{p,C}$

$C_{p,C}$ denotes the specific heat of CO_2. Specific heat value of CO_2 is given by [5] and adopted as a new parabola by using hoerl model.

$$C_{P,C} = (0.1874) \times 1.000061^T \times T^{0.2665} \tag{31}$$

3.2.4. Flue gas specific exergy value

The flow exergy of flue gas can be expressed in the ratio form as [6]

$$\psi = (h - h_0) - T_0(s - s_0) \tag{32}$$

where ψ is the flow exergy or the availability of stream flow neglecting K.E & P.E, s is the specific entropy and the subscript zero indicates the properties at the dead state of P_0 and T_0.

Entropy difference can be expressed in the form as

$$s - s_0 = C_p \ln\frac{T}{T_0} - R_{ave.}\ln\frac{P}{P_0} \tag{33}$$

$$R_{ave} = \frac{K_C(0.6927) + K_N(0.2968) + K_H(4.1249) + K_S(0.2596) + K_M(0.4615) + m_{air.steo}(0.2201)}{m_{fluegas}} + \frac{m_{air.steo.}(n-1)(0.287))}{m_{fluegas}} \tag{34}$$

where, R_{ave} is the average universal gas constant value of flue gas. Each gas has different gas constant. So, the average universal gas constants of combustion products are calculated and given in Eq. (35) [6]

$$\psi = C_{p,fluegas}(T - T_0) - T_0(C_{P,fluegas}\ln\frac{T}{T_0} - Rave.\ln\frac{P}{P_0}) \tag{35}$$

$$\psi = C_{p,fluegas}(T - T_0) - T_0 C_{p,fluegas}(\ln\frac{T}{T_0} - \frac{Rave.}{C_{p,fluegas}}\ln\frac{P}{P_0}) \tag{36}$$

$$\psi = C_{p,fluegas}[(T - T_0) - T_0(\ln\frac{T}{T_0} - \frac{Rave.}{C_{p,fluegas}}\ln\frac{P}{P_0})] \tag{37}$$

When $P \equiv P_0$,

General exergy flow equation can be written as:

$$\psi = C_{p,fluegas}[(T - T_0) - T_0(\ln \frac{T}{T_0})] \quad (38)$$

3. 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[8]. The calorific value of a fuel can be determined either from their chemical analysis or in the laboratory[9]. In the laboratory Bomb Calorimeter is used. The analysis of some sample of wastes from the Energy Centre, UNN using *Bomb Calorimeter* are shown in Table 5

Table 5 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. $= 29.986^0 C$ Final Temp. $= 31.009^0 C$ $\Delta T = 1.023^0 C$	Initial Temp. $= 29.933^0 C$ Final Temp. $= 30.981^0 C$ $\Delta T = 1.048^0 C$	Initial Temp. $= 28.743^0 C$ Final Temp. $= 30.457^0 C$ $\Delta T = 1.714^0 C$	Initial Temp. $= 29.015^0 C$ Final Temp. = $30.695^0 C$ $\Delta T = 1.68^0 C$
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
$\Phi = 4.5 * 2.3 = 10.35$	$\Phi = 6.5 * 2.3 = 14.95$	$\Phi = 5.7 * 2.3 = 13.11$	$\Phi = 6.7 * 2.3 = 15.41$
$V = 2.3$	$V = 2.5$	$V = 3.9$	$V = 3.8$
$E = 13039.308$	$E = 13039.308$	$E = 13039.308$	$E = 13039.308$
$CV_p = (E\Delta T - \Phi - V)/m$	$CV_w = (E\Delta T - \Phi - V)/m$	$CV_p = (E\Delta T - \Phi - V)/m$	$CV_p = (E\Delta T - \Phi - V)/m$
$CV_P = 12572.22 J/g$	$CV_w = 14012.05 J/g$	$CV_P = 21833.26 J/g$	$CV_P = 20551..01 J/g$
= 12572.22KJ/kg	= 14012.05KJ/kg	= 21833.26KJ/kg	= 20551.01KJ/kg

(SOURCE; National Centre For Energy Research & Development (NCERD), UNN.)

For chemical analysis, using *Dulong's formula,* percentage by mass was considered and heat of combustion of Carbon, Oxygen and Hydrogen determined as shown in Table 6

Table 6 Heat of combustion for C, S and H

Combustion	Heat of Combustion
$C + O_2 \rightarrow CO_2$	8075kcal/kg
$S + O_2 \rightarrow SO_2$	2220kcal/kg
$H_2 + \frac{1}{2} O_2 \rightarrow H_2O$	34500kcal/kg

(Source: P.Chattopadhyay, 2006)

Dulong suggested a formula for the calculation of the calorific of the fuel from their chemical composition as

$CV_{msw} = 8075(K_C) + 2220(K_S) + 34500(K_H - K_O/8)$ (39)

where K_C, K_S, K_H and K_O stand for percentage by mass of Carbon, Sulphur, Hydrogen and Oxygen respectively. Substituting the values of K_C, K_S, K_H and K_O from Table 2 will give,

$CV_{msw} = 8075(0.355) + 2220(0.005) + 34500(0.051-0.239/8)$

$CV_{msw} = 3,606.5 Kcal/kg$ (40)

$CV_{msw} = 15,101$ KJ/kg - - - - - - - - - (1cal = 4.187J)

Figures 2,3 & 4 show the views of the municipal waste steam boiler

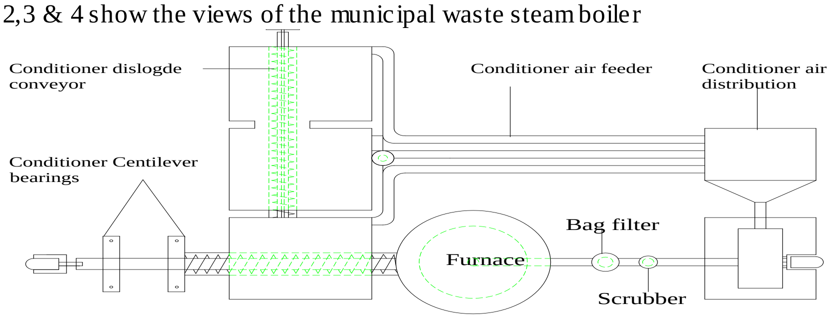

Figure 2 TOP VIEW OF MSW STEAM BOILER

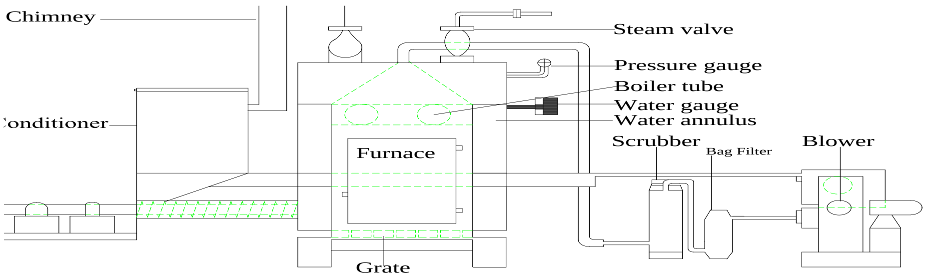

Figure 3 FRONT VIEW OF MSW STEAM BOILER

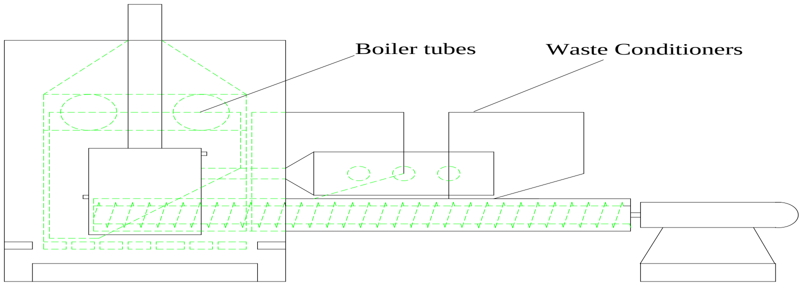

Figure 4 SIDE VIEW OF MSW STEAM BOILER

4.0

Results and Discussion

The Engineering Equation Solver (EES), developed at University of Wisconsin was used to obtain the solution of the equations.

4.1 Parameters for solution of the municipal solid waste-boiler design equations

The results of the calculated parameters for municipal solid waste design equations from the previous section are shown in table 6

Table 6 Parameters for solution of the municipal solid waste-boiler design equations

S/N	Symbols	Calculated data	S/N	Symbols	Calculated data
1	A_c [m^2]	0.1971	31	m_{uf}[kg]	0.326
2	A_{cyl} [m^2]	0.4058	32	O_2 [%]	80
3	A_{inc} [m^2]	0.9553	33	P[N/m^2]	10^6
4	A_{tubes} [m^2]	0.01623	34	Q_{bw}[kJ]	134.6
5	BHP[kW]	0.2587	35	$\dot{Q}_f$ [KW]	2098
6	CP_{fg} [kJ/kg]	1.047	36	$\dot{Q}_{fg}$ [m^3/s]	2.841
7	CV_{msw} [KJ/kg]	15101	37	Q_f [kJ]	10178
8	D_c[m]	0.5529	38	Q_{fg} [kJ]	5235
9	D_{inc}[m]	0.7188	39	Q_{ls}[kJ]	9578
10	D_{oc}[m]	0.8343	40	Q_r[kJ]	6504
S/N	**Symbols**	**Calculated data**	**S/N**	**Symbols**	**Calculated data**
11	D_{tubes}[m]	0.07188	41	Q_s[kJ]	1269
12	E [kg/kg]	4.049	42	Q_{uf} [kJ]	1900
13	eff.[%]	60.52	43	ℓ_{fg} [kg/m^3]	0.4723
14	H[m]	7.02	44	r_1[m]	0.005643
15	H_1 [kJ/kg]	763	45	r_c [m]	0.05634
16	H_2[kJ/kg]	2778	46	S_t [N/m^2]	1.360×10^8
17	h_{fg} [m]	10.59	47	t [m]	0.005947
18	H_{inc} [m]	7.014	48	T_a [K]	298
19	h_o [m]	0.7099	49	T_o [K]	298
20	H_{tubes} [m]	0.7188	50	T_{fg} [K]	833.7
21	h_w [mm]	5	51	T_{mit} [m]	0.0507
22	h_{wmax} [m]	4.158	52	τ_r [s]	1.002
23	K [W/mK]	0.04	53	T_w [m^3]	550
24	m_{air} [kg]	8.66	54	V_{fgc} [m^3]	14.41
25	$\dot{m}_a[kg/s]$	1.203	55	V_{inc} [m^3]	2.835
26	$\dot{m}_{fg}[kg/s]$	1.342	56	V_T [m^3]	7
27	$\dot{m}_{msw}[kg/s]$	0.1389	57	V_{water} [m^3]	1
28	$\dot{m}_{st}[kg/s]$	0.63	58	q[kW/m^2]	2264
29	m_f [kg]	0.674	59	$\dot{Q}_{st}$ [kW]	1269
30	m_{fg} [kg]	9.334	60	q_v[KW/m^3]	739.9
			61	Ψ[KJ/Kg]	209.2

4.2 Influence Of Specific Heat Capacity And Specific Exergy Value Of Flue Gas On Combustion

Considering the chemical composition of municipal solid waste used as a fuel, excess air amount and flue gas temperature which directly affect flue gas specific heat and exergy, variation of flue gas specific heat and exergy with furnace temperature for difference in values of excess air were done as shown in figs.5 and 6. From the figures, with increase in excess ratio, both flue gas specific heat and exergy decrease.

Table 7: Results For Variation Of Flue Gas Specific Heat With Furnace Temperature For Difference In Values Of Excess Air Ratio.

CP_{fgas} (KJ/KgK)	n	T_{fg} (K)	CP_{fgas} (KJ/KgK)	n	T_{fg} (K)	CP_{fgas} (KJ/KgK)	n	T_{fg} (K)
0.8460	1	700	0.7737	1.2	700	0.7128	1.4	700
0.8989	1	1100	0.8220	1.2	1100	0.7573	1.4	1100
0.9491	1	1300	0.8679	1.2	1300	0.7996	1.4	1300
0.9976	1	1500	0.9123	1.2	1500	0.8405	1.4	1500
1.0450	1	1700	0.9558	1.2	1700	0.8806	1.4	1700
1.0920	1	1900	0.9987	1.2	1900	0.9201	1.4	1900
1.1390	1	2100	1.0410	1.2	2100	0.9593	1.4	2100
1.1850	1	2300	1.0840	1.2	2300	0.9984	1.4	2300
1.2310	1	2500	1.1260	1.2	2500	1.0370	1.4	2500
1.2780	1	2700	1.1690	1.2	2700	1.0770	1.4	2700

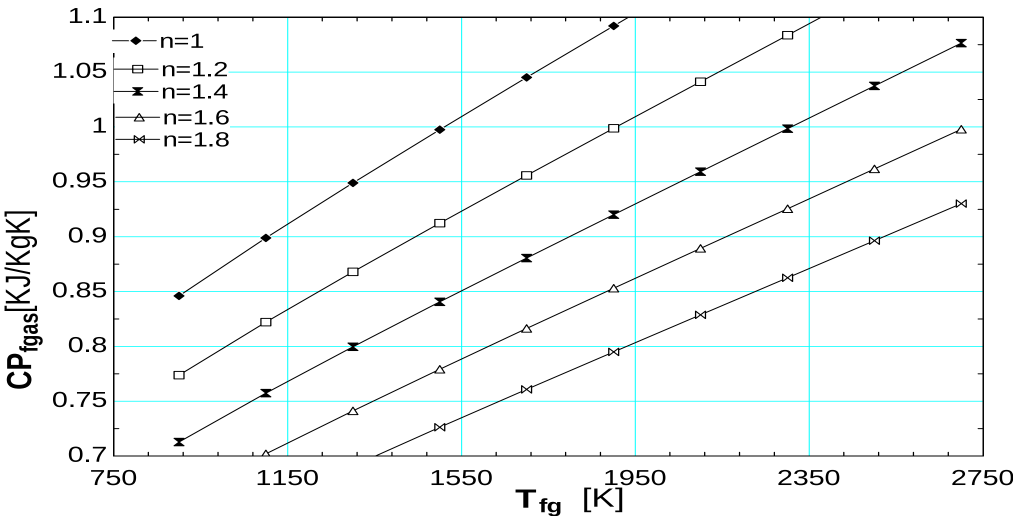

Figure 5: Variation of flue gas specific heat with furnace temperature for difference in values of excess air ratio.

Table 8: Results for Variation of flue gas specific exergy with furnace temperature for difference in values of excess air ratio.

Ψ [KJ/Kg]	n	T_{fg} (K)	Ψ [KJ/Kg]	n	T_{fg} (K)	Ψ [KJ/Kg]	n	T_{fg} (K)
230.6	1	700	210.9	1.2	700	194.3	1.4	700
371.1	1	1100	339.4	1.2	1100	312.6	1.4	1100
534.4	1	1300	488.7	1.2	1300	450.2	1.4	1300
718.7	1	1500	657.2	1.2	1500	605.5	1.4	1500
923.0	1	1700	844.1	1.2	1700	777.6	1.4	1700
1147.0	1	1900	1049.0	1.2	1900	966.0	1.4	1900
1387.0	1	2100	1271.0	1.2	2100	1170.0	1.4	2100
1651.0	1	2300	1510.0	1.2	2300	1391.0	1.4	2300
1931.0	1	2500	1766.0	1.2	2500	1627.0	1.4	2500
2230.0	1	2700	2039.0	1.2	2700	1879.0	1.4	2700

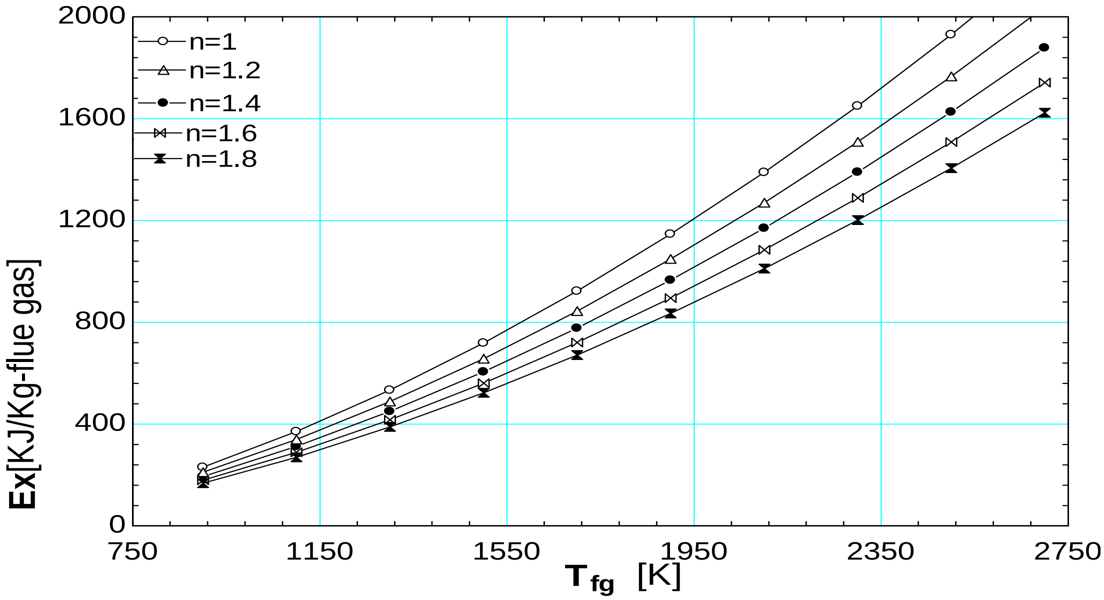

Figure 6: Variation of flue gas specific exergy with furnace temperature for difference in values of excess air ratio.

4.3 Influence Of Moisture Content

Wastes with different moisture contents have different drying characteristics. Those with higher moisture content require a longer drying time and much more heat energy, causing a lower temperature in the furnace; and vice versa. If the moisture content is too high, the furnace temperature will be too low for combustion, such that auxiliary fuel is needed to raise the furnace temperature and to ensure normal combustion. In order to evaluate the effect of moisture content on the combustion process, numerical simulation and analysis were made with ten different values of moisture content .The results of the analysis show that those wastes with a lower moisture content give rise to higher furnace temperatures and larger high-temperature zones during combustion, because the wastes with lower moisture contents have higher heating values and are more combustibles, being easier and faster to burn. Hence, to increase the efficiency of the boiler, refuse conditioner was used in this work to dry the wastes before they were conveyed to the furnace.

Table 9: Result for variation of flue gas Temperature with moisture content for difference in value of excess oxygen.

moisture	Excess O_2 (%)	T_{fg} (K)	moisture	Excess O_2 (%)	T_{fg} (K)	moisture	Excess O_2 (%)	T_{fg} (K)
0.030	5	2206	0.030	25	1941	0.030	45	1740
0.050	5	2115	0.050	25	1862	0.050	45	1670
0.070	5	2024	0.070	25	1782	0.070	45	1600
0.090	5	1932	0.090	25	1702	0.090	45	1529
0.011	5	1839	0.011	25	1622	0.011	45	1458
0.013	5	1749	0.013	25	1541	0.013	45	1387
0.015	5	1651	0.015	25	1460	0.015	45	1315
0,017	5	1557	0.017	25	1370	0.017	45	1243
0.019	5	1461	0.019	25	1295	0.019	45	1171
0.021	5	1365	0.021	25	1213	0.021	45	1098

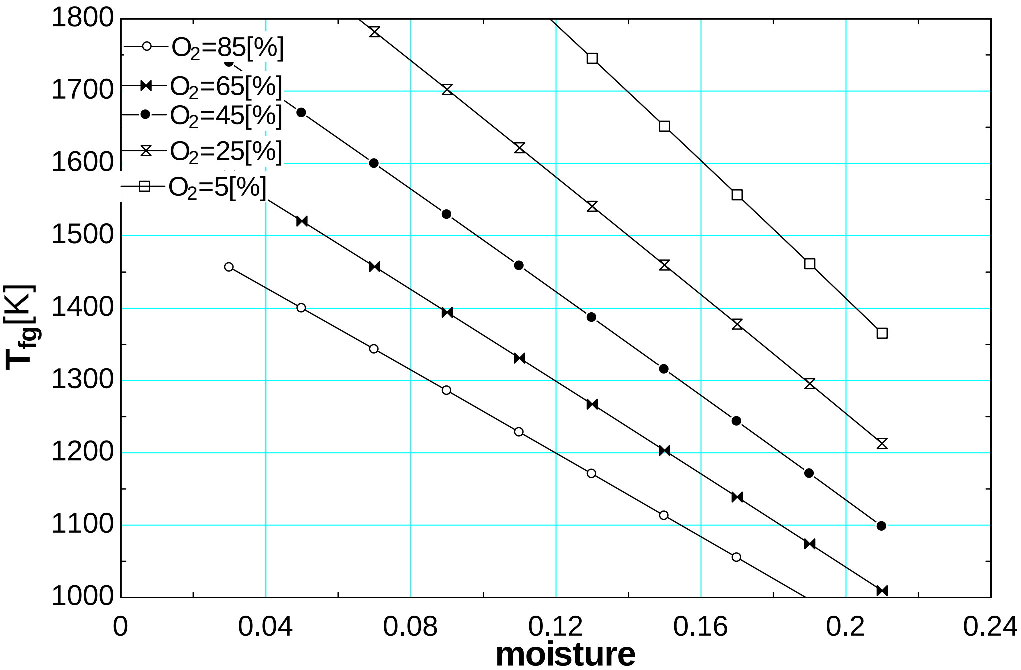

Figure 7: Variation of flue gas Temperature with moisture content for difference in value of excess oxygen.

4.4 Influence of excess air

The temperature in the furnace is closely related to MSW/air ratio. In order to predict the influence of excess air on the combustion in furnace, simulations were performed for different values of excess air. Results show that with the increase of excess air, the temperature of the furnace tends to decrease. To ensure adequate heating and burnout of wastes, a relatively high temperature level in the furnace should be maintained with a corresponding O_2 content.

Table 10 Result for variation of flue gas temperature with calorific value at different values of excess air

T_{fg} (K)	CV_{msw} (KJ/kg)	Excess O_2(%)	T_{fg} (K)	CV_{msw} (KJ/kg)	Excess O_2(%)	T_{fg} (K)	CV_{msw} (KJ/kg)	Excess O_2(%)
759.10	8000	5	716.80	8000	17	681.70	8000	29
817.10	9000	5	769.60	9000	17	730.00	9000	29
875.20	10000	5	822.30	10000	17	778.30	10000	29
933.20	11000	5	875.00	11000	17	826.60	11000	29
991.30	12000	5	927.80	12000	17	874.90	12000	29
1049.00	13000	5	980.50	13000	17	923.20	13000	29
1107.00	14000	5	1033.00	14000	17	971.50	14000	29
1165.00	15000	5	1086.00	15000	17	1020.00	16000	29
1223.00	16000	5	1139.00	16000	17	1068.00	17000	29
1283.00	17000	5	1191.00	17000	17	1116.00	18000	29

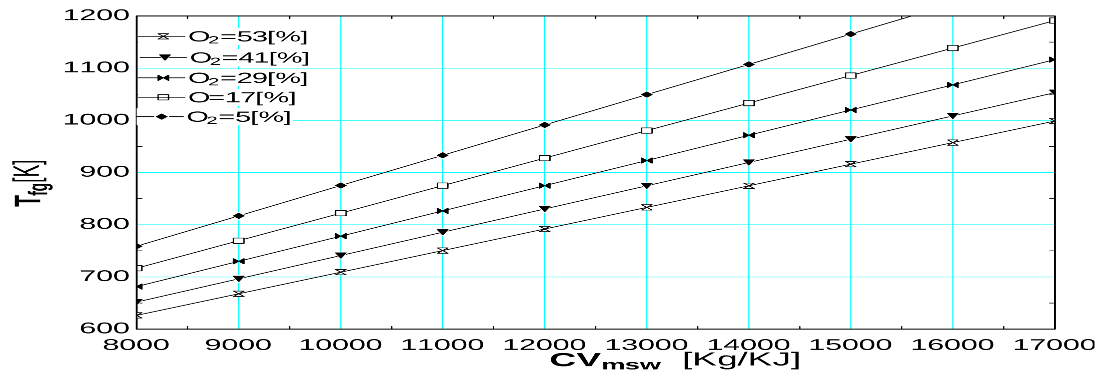

Figure 8 Variation of flue gas temperature with calorific value at different values of excess air.

5. Conclusions

With the rapid development of national economy, the ever-accelerating urbanization and the continued improvement of living standard, the output of the solid waste, particularly Municipal solid waste is constantly increasing. This causes environmental pollution and potentially affects people's health, preventing the sustained development of cities and drawing public concern in all of the society. The continuously generated wastes take up limited land resources, pollute water and air, and consequently lead to serious environmental trouble. Proper waste treatment is therefore an urgent and important task for the continued development of cities In this work, calculation of calorific value of municipal waste has been carried out from the elemental composition of the waste using Dulong's formula. The result of 15,101 KJ/kg obtained agrees with type 1 waste, N.T.Engineering,[10] that contains 25 percent moisture contents from waste classifications. With this heating value, maximum temperature of the flue gas of 833.7K was calculated from the heat balance equation in the furnace. Thermal analysis of the municipal solid waste boiler done with the operational conditions taken into account, showed that the municipal solid waste with higher moisture content has a lower heating value, corresponding to a lower temperature in the furnace and a lower O_2 consumption during combustion, resulting in a higher O_2 content at the outlet. Hence, for an efficient use of municipal solid waste as a fuel for generation of steam in boiler, waste with lower moisture content and adequate excess air supply should be used. In practical operation, the air supply rate and the distribution of the primary air along the grate should be duly adapted for the specific conditions of the wastes. An appropriate excess air ratio can effectively ensure the burnout of combustibles in the furnace, suppressing the formation and the emission of pollutants.

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