ACTA TECHNICA CORVINIENSIS
– Bulletin of Engineering
Tome X [2017]
Fascicule 1 [January – March]
ISSN: 2067 – 3809

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DEVELOPMENT OF COMPUTER PROGRAM FOR DESIGN OF A SCALABLE COMBUSTION FURNACE USING PALM KERNEL SHELL AS HEAT SOURCE

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Abstract: Steam boiler is an integral and important component of steam turbine used for electricity generation. Its design is however complex, time consuming and prone to errors if done manually. In this study, we report the application of computer based approach to design palm kernel shell combusting furnace for generating a desired amount of electricity. Using backward calculation approach, standard design equations were used to size furnace and its components. The equations were coded and solved using C-Sharp programming language. The results showed that to generate 5 kW of electricity from palm kernel shell; 5.5 kW turbines, 3.6 m super heater, 3.2 m riser, furnace of 1.432 m height and 0.45 m^3 volume were required having considered power loss due to friction and others. While these results are in good agreement with those calculated manually, human errors are virtually eliminated. In addition, calculations and drafting time were reduced from 5 hrs 47 mins when done manually to about 4 mins when the developed code was used. This code can be used to size boiler for any desired power output.

Keywords: Steam boiler, palm kernel shell, design, computer aided, power output

INTRODUCTION

In palm oil processing industry, biomass residues can be converted from being potential environmental pollutants to useful fuel for steam and electricity generation which are largely needed for industrial use [22]. Nigeria, being the fifth largest producer of palm oil, accounts for about 1.5 % (93 0,000 metric tonnes) of the global output. However, a huge quantity of oil palm residues which could otherwise be used for energy generation is being wasted [11]. Muhammad et al. [14] reported that about 30 tonnes of fresh fruit bunches /hr produce from a few palm oil mills can be used to generate up to 20 - 35 MW of electricity. This can significantly reduce greenhouse gases and increase employment for local population [21].

There are several technologies that enable oil palm mill to generate enough energy for its consumption and sometimes for export. Among them are fixed (1 kW- 50 MW), fluidized (5 MW- 100 MW) and dust technology (10 MW- 500 MW). Efficiencies of these technologies are dependent on fuel properties and the mixing quality between flue gas and combustion air [20]. Another researcher [17] recorded high combustion efficiency and low emission performance in a fluidized bed combustion of palm kernel shell using optimized particle size, although the start up and running cost of operation associated with this technique make it difficult to be operated by small scale business. Remarkable improvement has also been recorded on design of large scale grate furnaces (fixed bed), yet additional work need to be done in small scale businesses in term of poor mixing especially when co-firing different fuel and high moisture fuel content for improve combustion and reduction of ash deposition on components of grate furnace [15]. The unique features of grate furnace are the tolerance of fuel type; positive movement of fuel down grates reduces blockages and well controlled air distribution lead to high combustion efficiency [23]. In addition, the use of additive mixed with solid wastes can significantly reduce alkaline metals deposition on the surface of riser tubes [13]. These will increase combustion process and decrease ash deposition.

Boiler design is a complex and time consuming procedure. It is also prone to errors if done manually. Previously, emphasis was laid on primitive and probabilistic design processes which resulted in high cost of production. Dimensions of boiler for power generation often depend on fuel and vaporization efficiency; the mass balance, heat balance and heat transfer which has to be specified through empirical results and experiences. In this paper, we report the application of computer based approach to design palm kernel shell combusting furnace for generating a desired amount of electricity using backward calculation approach.

MATERIALS AND METHOD

Palm Kernel Shell (PKS) were collected from a local palm oil processing mill in Ogbomoso, Southwestern Nigeria. The shells were crushed into smaller pieces by using a granulator (SG-16 Series) and further reduced with a blender. They were subsequently sieved to 5.0 mm particle size according to [17]. The proximate and ultimate analyses of the PKS were done following [2]. Higher Heating Value (HHV) of the mixtures was determined using GallenKamp Bomb Calorimeter according to [3].

Development of Grate Furnace and its Components

The furnace under consideration was based on principle of water tube natural circulation. The main components of this furnace are steam drum, downcomer, riser tubes which represents the complete fluid flow loop.

Water flows to the steam drum through downcomer riser loop. The riser tubes were situated inside furnace where heat of flue gases vaporizes the water into steam and back to the steam drum through steam header collection (Figure 1). Because steam water mixture inside riser tubes is less dense than the saturated water at inlet tube, fluid flows upwards in the riser tubes and back to the drum. The density difference between water at the inlet tube and steam-water mixture produces enough force to overcome friction and gravitational resistance to flow, therefore maintain a steam flow system [4].

The steam drum is partitioned into two zones. The lower section allows water intake to the drum while the upper section produces steam which flows from the top of the drum into the superheater tube. The superheated steam is expected to turn turbine to generate electricity. The design analysis follows backward calculation approach of sizing the power plant component to generate steam for 5 kW of electricity (Generator – Turbine – Superheater – Riser tubes – Furnace dimensions). The design approach to each component is described in the following sections.

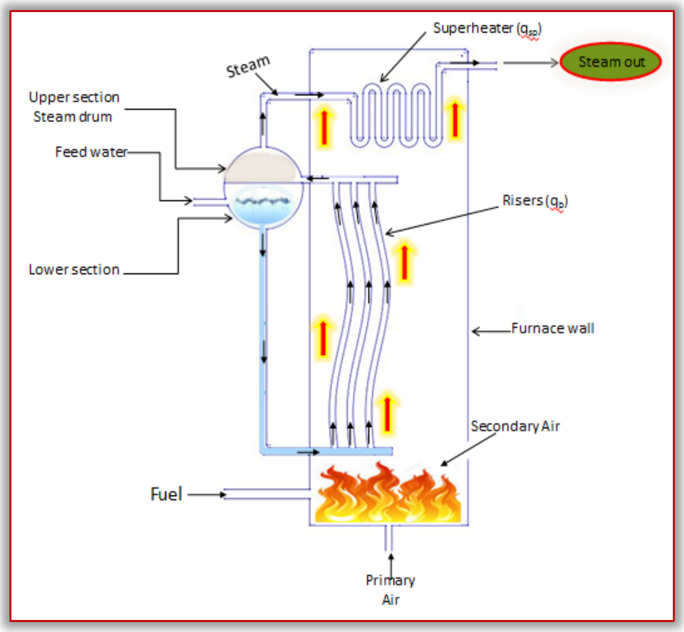


Figure 1: Schematic diagram describing water to steam circulation loop

Turbine: is a rotary engine that converts the energy of the steam, water or gas into mechanical energy. The mechanical energy is then transferred through a driven shaft to power electric generator.

The power input from turbine P_{turb} can be related to the power output of generator P_{out} by Eq. (1).

$$P_{turb} = P_{out} + P_{loss} \tag{1}$$

The generator efficiency η_{gen} is calculated from Eq. (2).

$$\eta_{gen} = \frac{P_{out}}{P_{out}+P_{loss}} \tag{2}$$

where,

$$P_{loss} = P_{mechanical} + P_{I^2R\ loss}$$

The mass flow rate of steam m_s from superheater entering turbine was estimated using energy equation for adiabatic expansion which relates the power output to steam energy declining by passing through the turbine [5].

$$m_s = \frac{P_{turb}}{C_{pm}\,\eta(T_{in}-T_{out})} \tag{3}$$

For steam: c_p = 1.8723 kJ/kgK and c_v = 1.4108 kJ/kgK.

But, $\gamma = \frac{C_p}{C_v}$, therefore:

$$T_{out} = T_{in}\left(\frac{P_{out}}{P_{in}}\right)^{\frac{\gamma-1}{\gamma}} \tag{4}$$

where, T_{in} is the inlet steam temperature, T_{out} is the outlet steam temperature, γ is the index number C_p is the specific heat capacity of steam at constant pressure and C_v is the specific heat capacity of steam at constant volume C_{pm} is the mean specific heat capacity of steam.

For 5 kW power rating, T_{in}, P_{in} and P_{out} are chosen as 400°C, 0.1 MPa and 0.45 MPa, respectively. These were the state properties of steam turbines obtained from V-FLO Pump and System, Beijing, China (www.v-flo.com).

Coulson and Richardson [6] defined the mean specific heat capacity C_{pm} over the temperature range T_1 to T_2 by Eq. (5).

$$C_{pm} = \frac{\int_{T_1}^{T_2} C_p dT}{\int_{T_1}^{T_2} C_p dT} \quad (5)$$

The specific heat capacity (C_p), as a function of temperature, is given by Eq. (6)

$$C_p = a + bT + cT^2 + dT^3 \quad (6)$$

Superheater: Is heat exchanger that transfers heat energy from a heating medium to a heated medium. The heating medium is usually flue gas while the heated medium is steam. An energy balance equation of super heater is:

$$q_{sp} = m_s C_{pm}(T_{sp} - T_s) \quad (7)$$

where, $q_{sp}$is the heat duty required by the superheater, T_{sp} and T_s is the temperature of superheated and saturated steam from superheater and boiler respectively.

The energy balance equation of the riser tube is given by Eq. (8):

$$q_b = m_s c_p(T_s - T_d) + x_s m_s L \quad (8)$$

Assuming the water from down comer is saturated T_d = 100 C, and T_s = 100 C; steam is in equilibrium with water in the riser. T_s = T_d =100 C, Therefore

$$q_b = x_s m_s L \quad (9)$$

where, q_b is the heat duty required by the riser tube, L is the specific latent heat of vaporization

x_s is the dryness fraction of steam/water mixture

$$q_f = m_{fuel} \times LHV \quad (10)$$

where, m_{fuel} is the mass of the fuel, q_f is the heat liberated by the fuel

$$m_{air} = \text{Air} - \text{fuel ratio} \times m_{fuel} \quad (11)$$

Furnace volume: Chungen et al., [7] documented typical value of volumetric heat release rate (q_v) for biomass as 0.176 MW/m³. Similarly, [19] reported furnace strain level largely depends on different fuels and if the electric power of the plant is known, strain levels for volume can be chosen.

The furnace volume V, grate area A and furnace height h can be obtained from Eq. (12), Eq. (13) and Eq. (14), respectively.

$$V = \frac{q_f}{q_v} \quad (12)$$

$$A = \frac{\pi d^2}{4} \quad (13)$$

$$h = \frac{V}{A} \quad (14)$$

Sizing of riser and superheater:

The heat duty required in the riser is given by:

$$q_b = UA\Delta T_{LM} \quad (15)$$

And the overall heat transfer (U) based on the outside area (A) of the riser tube can be estimated as;

$$\frac{1}{U} = \frac{1}{h_g} + \frac{t_r}{k_w} + \frac{1}{h_b}\left[\frac{d_o}{d_i}\right] \quad (16)$$

where: h_g is the heat transfer coefficient of flue gas, t_r is the wall thickness of riser tube, k_w is the thermal conductivities of stainless steel (304), d_o and d_i are internal and external pipe diameter, h_b is the heat transfer coefficient of water boiling.

The analysis of heat transfer associated with flow past the exterior surface of a solid is a complicated situation due to boundary layer separation [10]. Nusset number can also be used to calculate heat transfer coefficient of flue gas (h_g).

Specific heat capacity, dynamic viscosity and thermal conductivity of flue gas

Verbanck [24] determined specific heat capacity of flue gas (C_{pg}) as the summation of the product of the mass fraction of each component of flue gas m_k (kg/kg) by its respective specific heat at the relevant temperatures c_k (kJ /kg°C) as:

$$C_{pg} = \sum m_k c_k \quad (17)$$

$$c_k = A + BT + CT^2 \quad (18)$$

Hassan and Ibrahim [9] stated that heat losses through casings must be accounted for if accurate computation of flame temperature is to be made. This was done by setting up heat balance equation for flue gas as follows:

$$Q_{combustion} - Q_{loses} = \sum C_{pg} \times m_g \times (T - T_{air}) \quad (19)$$

where; $$Q_{combustion} = m_{fuel} \times LHV \quad (20)$$

According to [9],

$$Q_{loses} = 5\% \times Q_{combustion} \quad (21)$$

The dynamic viscosity μ_g of flue gas is obtained from Eq. (22) by [24]:

$$\mu_g = \sum \frac{\mu_k m_k}{\sqrt{M_k}} \div \sum \frac{m_k}{\sqrt{M_k}} \quad (22)$$

Thermal conductivity of the flue gas(k_g) was determined from Eq. (23) according to [8]

$$\frac{k_g}{\mu_g C_v} = 1.32 + \frac{1.77R_g}{C_v} \quad (23)$$

$$C_v = C_{pg} - R_g \quad (24)$$

From Eq. (23) and Eq. (24), we have;

$$k_g = \mu_g(C_{pg} - R_g)\left[1.32 + \frac{1.77R_g}{C_{pg} - R_g}\right] \quad (25)$$

where, R_g is the characteristic gas constant of flue gas,

R_{CO_2} =188, R_{O_2} = 260, R_{H_2O} = 462,

R_{N_2} = 297, R_{SO_2} = 130

C_v is the specific heat capacity of flue gas at constant volume

Prandtl and Reynolds numbers of the flue gas

The Prandtl number P_r and Reynolds number Re_D of flue gas are given by Eq. (26) and Eq. (27), respectively.

$$P_r = \frac{\mu_g C_{pg}}{k_g} \quad (26)$$

$$Re_D = \frac{m_g d_b}{\mu_g A_{cr}} \quad (27)$$

where, A_{cr} is the crossectional area of flow of flue gas, D is the diameter of riser tube

For an external cross flow to a cylindrical pipe, the Reynolds number range 40-4000 and P_r ≥ 0.7, the average corresponding Nusselt Number according to [10] is given by:

$$\overline{NU_D} = 0.683 Re_D^{0.466} P_r^{1/3} \quad (28)$$

$$\overline{NU_D} = \frac{h_g D}{k_g} \quad (29)$$

The empirical equation proposed by [12] for the calculation of heat transfer coefficient of water boiling h_b is as follow

$$h_b = 2.8 P^{0.176} q^{0.7} \quad (30)$$

valid at $0.2bar \leq P \leq 98bar$

where, $q = \text{heat flux} \frac{W}{m^2} = \frac{q_b}{A_s}$, P is the saturated pressure, A_s is the surface area of riser

Evaluation of logarithmic mean temperature (ΔT_{LM})

Heat obtained by the riser is the heat given out by the flue gas

$$q_b = m_g C_{pg} (T_{gin} - T_{gout}) \quad (31)$$

For a cross flow heat exchanger, [19] gives the Logarithmic Mean Temperature Difference as follow

$$L_{MTD} = \frac{(T_{gin} - T_{so}) - (T_{gout} - T_{sin})}{\left| \frac{T_{gin} - T_{so}}{T_{gout} - T_{sin}} \right|} \quad (32)$$

where; T_{gin} is the temperature of flue gas in,
T_{gout} is the temperature of flue gas out,
T_{so} is the temperature of saturated steam out

From the equation (15) the total heat transfer surface area A_s is given by;

$$A_s = \pi dL \quad (33)$$

Where; d_o = outside diameter of tube (m) and L = length of tube (m).

Software development: Based on equations (1-33) an algorithm was written and then translated to computer code using C# programming language and .Net framework. The flow chart upon which the algorithm was based is shown in Figure 2.

The code receives input parameters in order to size components for 5 kW of electricity and gives dimensions of furnace, riser and superheater tube as outputs. In addition, 2D drafting of combusting furnace was done in AutoCAD and was dynamically loaded into the Visual Studio workspace of the application.

It should be noted that .Net frame work was selected because of its ease of deployment, interoperability, and automatic management of resources and cross platform support. Here is the algorithm for the software development:

(a) Enter the electrical output power in kW and efficiency of synchronous generator in (%) from design requirement;
(b) The properties of the PKS based on its ultimate analysis (i.e. carbon, hydrogen, oxygen nitrogen and sulphur) were supplied;
(c) The mass fraction of the flue gas component and the mean specific heat of the flue gas component available were stored in the software database; Submit to compute for turbine parameters;
(d) Click on further calculations on furnace, heat transfer coefficient of flue gas and heat transferred on super heater and riser tube; submit to compute furnace parameters, convection coefficient and length of superheater and riser tube; and when all conditions required for sizing furnace components have been adequately satisfied with respect to the calculation to the four steps above, the design parameters are then used to draft the 2D of the furnace. This is done through drafting modules wherein the geometries has been mathematically represented within the developed software.

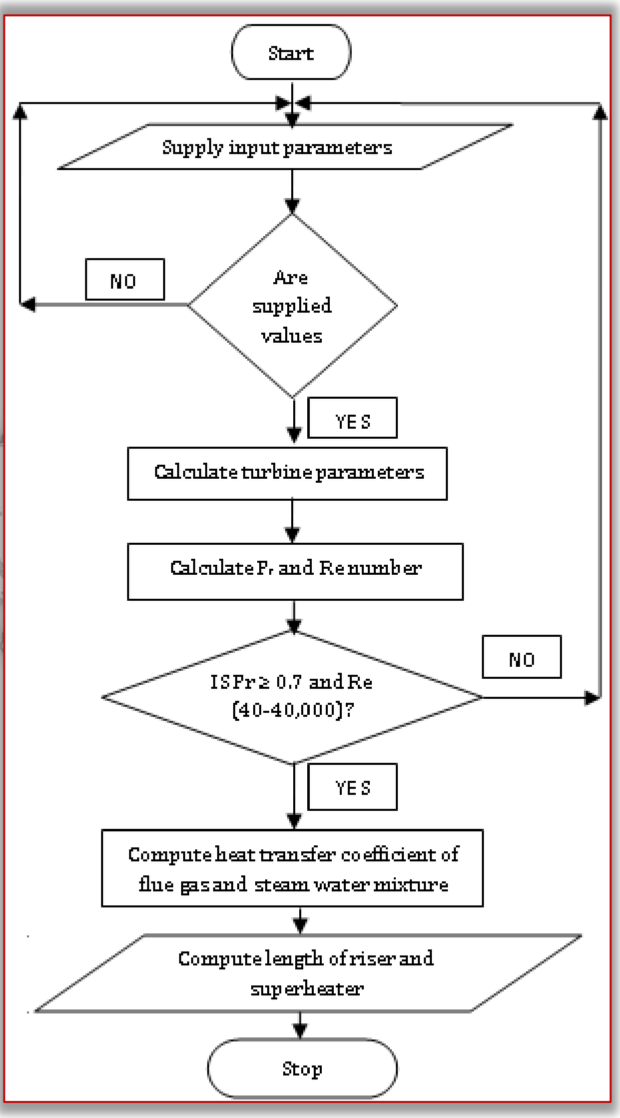


Figure 2: Flowchart showing sizing of PKS combusting furnace

Fabrication and assembly of steam boiler: The components of the boiler developed are superheater, riser, water tank, drum, and furnace chamber. Figure 3 depict the exploded view of PKS combustion unit. The fabrication process, material selection and cost analysis for each component' are reported elsewhere.

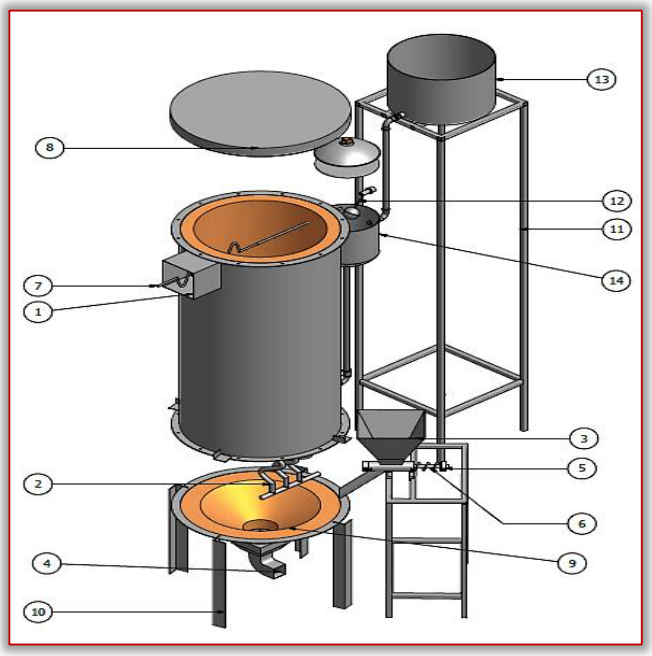


Figure 3: Exploded view of PKS Combusting Furnace

Item	Qty	Part list
1	1	Superheater port
2	3	Riser
3	1	Hopper
4	1	Primary air inlet
5	2	Ball bearings
6	1	Auger
7	1	Superheater
8	1	Furnace cover
9	1	Bricks
10	1	Furnace stand
11	1	Water tank stand
12	1	Water level valve
13	1	Water tank
14	1	Drum

RESULTS AND DISCUSSIONS

Proximate and ultimate analysis

The proximate analysis of the sample of PKS collected from a local oil palm mill in Iresapa Ogbomoso Southwestern, Nigeria (Table 1) showed moisture content, volatile matter, fixed carbon, and ash of 2.70 %, 44.20 %, 52.79 % and 0.31 %, respectively. These results are largely different from those of [16]. It can be seen that this biomass contain low moisture and ash content which resulted to substantial higher heating value of the shell while compared to [16].

Similarly, the ultimate analysis (Table 2) shows that percentage weight of oxygen and hydrogen content in this study are higher while carbon, sulphur and nitrogen content are lower compared to those of [16]. This might be due to the variations in the species, location, soil type, climatic condition of the palm kernel shell sourced.

Table 1: Proximate Analysis
(% by weight on dry basis) *[16]

Property	This study	[16]*
Moisture	2.70	5.40
Volatile matter	44.20	71.10
Fixed Carbon	52.79	18.80
Ash	0.31	4.70

Table 2: Ultimate Analysis
(% by weight on dry basis) *[16]

Roperty	This study	[16]*
Carbon	45.12	48.06
Hydrogen	10.67	6.38
Nitrogen	0.27	1.27
Oxygen	40.11	34.10
Sulphur	0.62	0.09
LHV (MJ/kg)	15.17	

Component dimensions based on the developed software

The graphical user interface for sizing turbine parameters is shown in Figure 4. The input parameters, which are the output power, efficiency of generator and location of PKS used, are provided.


Steam Generator 1

Output Power : KW
Efficiency of generator %
Location of Fuel Used
Components

	Name	Mk	A	B	C

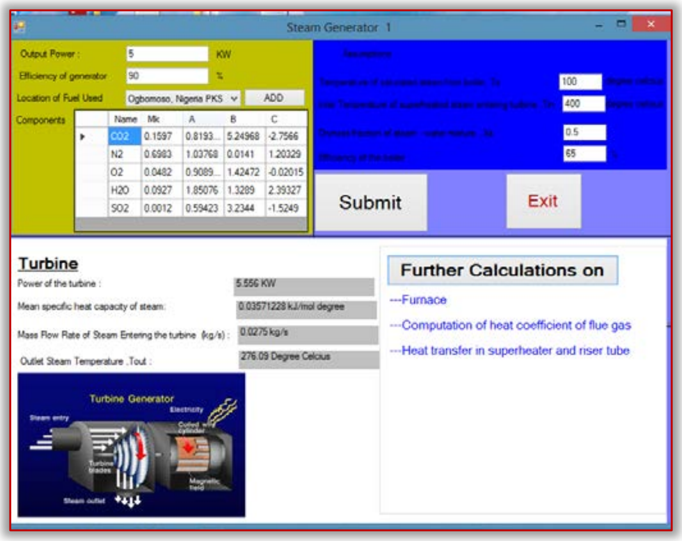
100
400
0.5
65

Turbine
Power of the turbine :
Mean specific heat capacity of steam:
Mass Flow Rate of Steam Entering the turbine (kg/s) :
Outlet Steam Temperature ,Tout :

Further Calculations on
---Furnace
---Computation of heat coefficient of flue gas
---Heat transfer in superheater and riser tube

Figure 4: Template for the Turbine Parameters

To obtain furnace parameters, length of riser and superheater tube, 'further calculation' bottom is clicked. For example, to size turbine components for 5 kW of electricity generation, the efficiency of a synchronous generator (90 %) is provided and Ogbomoso is selected as the location of PKS used. By clicking the 'submit' button, we obtained 5.56 kW of turbine, 0.0275 kg/s of steam entering turbine, 276.09 °C of outlet steam temperature and 0.03571 kJ/mol°C of mean specific capacity of the steam (Figure 5). These values are required to generate 5 kW of electricity. By clicking 'further calculations on furnace' heat transfer coefficient of flue gas and heat transferred on super heater and riser tube, and the furnace can be appropriately sized.



Steam Generator 1

Output Power : 5 KW
Efficiency of generator 90 %
Location of Fuel Used Ogbomoso, Nigeria PKS

Name	Mk	A	B	C
CO2	0.1597	0.8193...	5.24968	-2.7566
N2	0.6983	1.03768	0.0141	1.20329
O2	0.0482	0.9089...	1.42472	-0.02015
H2O	0.0927	1.85076	1.3289	2.39327
SO2	0.0012	0.59423	3.2344	-1.5249

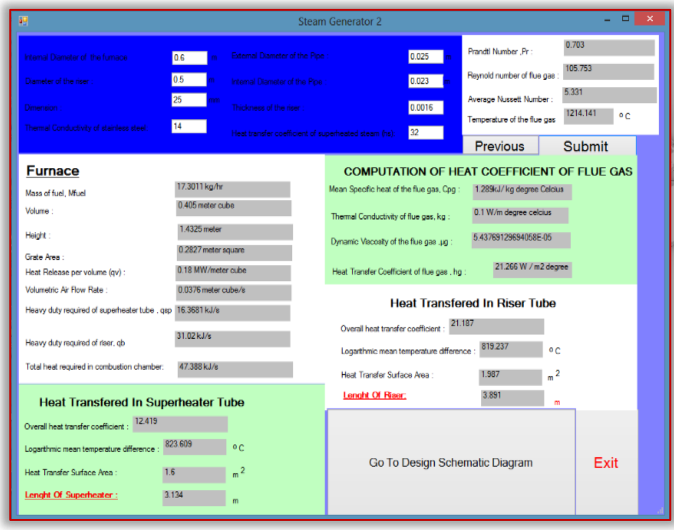
100
400
0.5
65

Turbine

Power of the turbine : 5.556 KW
Mean specific heat capacity of steam: 0.03571228 kJ/mol degree
Mass Flow Rate of Steam Entering the turbine (kg/s) : 0.0275 kg/s
Outlet Steam Temperature ,Tout : 276.09 Degree Celcius

Figure 5: Output Screen for the Turbine Parameters

For 5 kW; 17.36 kg/hr of fuel, 0.405 m³ volume, 1.432 m height and 0.0376 m³ volumetric air flow rate are needed (Figure 6).



Steam Generator 2

0.6 m
0.5 m
25 mm
14
0.025 m
0.023 m
0.0016
32

Prandtl Number ,Pr : 0.703
Reynold number of flue gas : 105.753
Average Nussett Number : 5.331
Temperature of the flue gas 1214.141 ° C

Furnace

Mass of fuel, Mfuel 17.3011 kg/hr
Volume : 0.405 meter cube
Height : 1.4325 meter
Grate Area : 0.2827 meter square
Heat Release per volume (qv) : 0.18 MW/meter cube
Volumetric Air Flow Rate : 0.0376 meter cube/s
Heavy duty required of superheater tube , qsp 16.3681 kJ/s
Heavy duty required of riser, qb 31.02 kJ/s
Total heat required in combustion chamber: 47.388 kJ/s

COMPUTATION OF HEAT COEFFICIENT OF FLUE GAS

Mean Specific heat of the flue gas, Cpg : 1.289kJ/ kg degree Celcius
Thermal Conductivity of flue gas, kg : 0.1 W/m degree celcius
Dynamic Viscosity of the flue gas ,μg : 5.43769129694058E-05
Heat Transfer Coefficient of flue gas , hg : 21.266 W / m2 degree

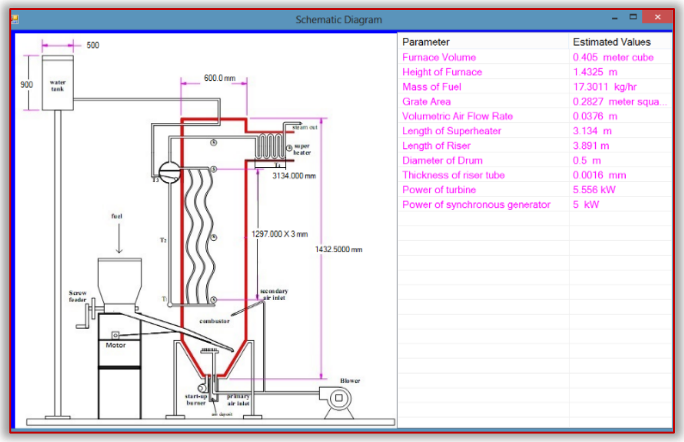
Heat Transfered In Riser Tube

Overall heat transfer coefficient : 21.187
Logarthmic mean temperature difference : 819.237 ° C
Heat Transfer Surface Area : 1.987 m 2
Lenght Of Riser: 3.891 m

Heat Transfered In Superheater Tube

Overall heat transfer coefficient : 12.419
Logarthmic mean temperature difference : 823.609 ° C
Heat Transfer Surface Area : 1.6 m 2
Lenght Of Superheater : 3.134 m

Figure 6: Output Screen for the Furnace parameters and Length of riser and superheater tube



Schematic Diagram

Parameter	Estimated Values
Furnace Volume	0.405 meter cube
Height of Furnace	1.4325 m
Mass of Fuel	17.3011 kg/hr
Grate Area	0.2827 meter squa...
Volumetric Air Flow Rate	0.0376 m
Length of Superheater	3.134 m
Length of Riser	3.891 m
Diameter of Drum	0.5 m
Thickness of riser tube	0.0016 mm
Power of turbine	5.556 kW
Power of synchronous generator	5 kW

Figure 7: Output Screen Schematic Drawings and Estimated Values of (5 kW) PKS Combustor

The equivalent designed PKS combusting furnace is shown in Figure 7. The software can be used to size furnace for generating specified power.

To validate the accuracy of the developed software, we compared the results obtained manually with those obtained via the software. The results are found to be very similar (Table 3).

Table 3: Comparison of manually calculated and software generated values on PKS furnace design

Parameters	Manually calculated values	Computer generated parameters
Power of the turbine	5.560 kW	5.556 kW
Mass flow rate of steam entering turbine	0.028 kg/s	0.028 kg/s
Outlet steam temperature	276.10 C	276.05 C
Specific heat capacity of steam	0.0362 kJ/mol°C	0.0357 kJ/mol°C
Mass of fuel	17.3 kg/hr.	17.301 kg/hr.
Volume of furnace	0.414 m³	0.405 m³
Grate Area	0.283 m²	0.287 m²
Height of furnace	1.4325 m	1.4325 m
Volumetric air flow rate	0.035 m³/s	0.035 m³/s
Diameter of drum	0.500 m	0.500 m
Thickness of riser tube	1.6 m	1.6 m
Heat duty of riser tube	31.01 kJ/s	31.02 kJ/s
Heat duty required of superheater	16.461 kJ/s	16.368 kJ/s
Total heat required in furnace	47.349 kJ/s	47.388 kJ/s
Length of riser tube	3.782 m	3.891 m
Length of superheater	3.135 m	3.135 m

Table 4: Data Sheet for Power Plant Components for 10 and 25 kW

Parameters	Rated Power	
Parameters and Estimated values	10 kW	25 kW
Power of the turbine (kW)	11.11	27.77
Mass flow rate of steam entering turbine (kg/s)	0.05	0.035
Specific heat capacity of steam (kJ/mol°C)	0.035	0.137
Mass of fuel (kg/hr)	34.60	86.53
Volume of furnace (m³)	0.81	2.026
Grate Area (m²)	0.28	0.282
Height of furnace (m)	2.86	7.167
Volumetric air flow rate (m³/s)	0.075	0.188
Thickness of riser tube (m)	0.002	0.002
Heat duty of riser tube (m)	62.04	155.21
Heat duty required of supreheater (kJ/s)	32.77	81.90
Total heat required in furnace (kJ/s)	94.77	237.13
Length of riser tube (m)	3.89	3.89
Length of superheater (m)	5.25	10.85

In terms of time saving, manual calculations and drafting of furnace components details took about 5 hrs 47 minutes while the same process was completed in 4 mins when the software was used. The software can be used to size furnace and its component for any desired output. Data sheet power plant component for 10 and 25 kW were shown in Table 4.

CONCLUSION

The developed software using C-sharp programming language automatically sizes the furnace and its components with two dimensional working drawings. The software outputs were compared to the manual computations, and the results were found similar.

For a fuel feed rate of 17.3 kg/hr and volumetric air flow rate of 0.00376 m^3/s; the temperature of flue gas, mean specific heat capacity of steam and outlet steam temperature required for 5 kW power rating were 1214 C, 0.0357 kJ/mol C, and 276.05 C respectively.

Manual calculations and drafting of furnace components details took about 5 hrs 47 mins while the same process was completed in 4 minutes when the software was used. In addition, inaccuracies due to human errors are virtually eliminated. However, cost analysis, fabrication process of the developed boiler and material selection were not reported, in addition the developed software is only suitable for sizing furnace and its components using oil palm wastes as a source of fuel.

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ISSN:2067-3809

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