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PERFORMANCE CHARACTERISTICS OF A MINIATURE FLUIDISED BED BOILER AS AN ALTERNATIVE FOR STEAM POWER GENERATION IN RURAL AREAS OF NIGERIA

M. B. Balogun,* C. O. Folayan, D. M. Kulla and F. O. Anafi

Department of Mechanical Engineering, Ahmadu Bello University, Zaria, Nigeria.
***Corresponding Author email: balo.muyi@gmail.com**

ABSTRACT
With the ever-growing energy demand over the globe, Nigeria's demand and utilization of power has been an on-going problem for decades with less than 40% of rural community connected to the national grid. The need to explore the usage of safe and naturally abundant materials whose relevance has largely been underestimated in power generation becomes non-negotiable in order to sustain the socioeconomic development. This paper presents performance of fluidised bed combustion boiler that depends on the fuel distribution in which agricultural waste solid fuel (corncob) was burnt at bed height of 77mm, 47 mm and 27 mm using 250 μm granular material. The results recorded stability in the superheated temperature of 141^oC at 55 minutes, 147^oC at 45 minutes and 163^oC at 30 minutes respectively. The maximum superheated pressure obtained were 2.1 bar at 55 minutes for bed height of 77mm, 2.6 bar from bed height of 47 mm at 45 minutes and 4.0 bar from bed height of 27 mm from 45 to 55 minutes. Lastly, emission analysis of the flue gas has shown to be low in various percentages of 0.0003% of NO_x, 0.001% HC and 0.02% of CO.
Keywords: *Corncob, Fluidized bed boiler, Superheated temperature, Electrification, Superheated pressure, Emission reduction.*

INTRODUCTION

Nowadays, technology offers several solutions and incentives to use different kinds of biomass fuels to produce energy. Technological developments over time have increased the ability to burn different kind of fuels by means of specific boiler concepts and the flexibility to burn different fuels in a boiler. A waste-to-energy plant takes profit from useless waste by converting it to energy, usually by incineration in a boiler in order to convert water to steam. There are different kinds of waste being incinerated in boilers such as household garbage from a society or by-products from the process industry and organic matters from agricultural waste (Koornneef *et al.*, 2007). The use of biomass as alternative sources of energy is attractive because it addresses both problems of waste disposal and fuel wood shortages, the extraction of useful energy from biomass could bring very significant social and economic benefits to both rural and urban areas (Kyauta *et al.*, 2015). Boilers are pressure vessels designed to heat water or produce steam, by combustion of fuel which can then be used to provide space heating and/or service water heating to a building (Odigure *et al.*, 2005). Steam is preferred over hot water in some applications, including absorption cooling, kitchens, laundries, sterilizers, and steam driven equipment (Ohijeagbon *et al.*, 2013).

The development of the fluidised bed technology over the years has allowed to achieve higher efficiency levels while reducing emissions and increasing fuel flexibility, which are key under current global market and environmental conditions. Fluidised bed combustion (FBC) is a combustion technology used to burn solid fuels. In its most basic form, fuel particles are suspended in a hot, bubbling fluidity bed of ash and other particulate materials (sand, limestone etc.) through which jets of air are blown to provide the oxygen required for combustion, the resultant fast and intimate mixing of gas and solids promotes rapid heat transfer and chemical reactions within the bed (Thenmozhi and Sivakumar, 2013). The fluidisation is created by the upward flow of combustion air and operating temperature of a fluidised bed boiler is narrow, around 800 – 900°C, lower temperatures lead to decreased boiler efficiency while a too high temperature can lead to ash sintering, causing the bed to clog (Johansson, 2012).

World energy supplies have been dominated by fossil fuels for decades. Today biomass contributes about 10–15% (or 45 ± 10 EJ) of this demand. On average, in the industrialised countries biomass contributes some 9–14% to the total energy supplies, but in developing countries this is as high as one-fifth to one-third (Khan *et al.*, 2009). According to the world energy council projections, if the adequate policy initiatives are provided in 2025, 30% of the direct fuel use and 60% of global electricity supplies would be met by renewable energy sources (Koh and Hoi, 2003).There are several benefits of introducing electricity to rural communities, while obvious reasons include social gains like lightening, cooking and water pumping, electricity will help to stem the flow of rural-urban migration which is a common problem in many developing countries like Nigeria. Introduction of electricity also helps to provide productive employment in rural areas thereby creating a positive impact on economic as well as social growth (Folayan *et al.*, 2015).

Folayan *et al*. (2015) discuss the environmentally friendly methods of extracting biomass energy for rural use. One such means is energy recovery using fluidised bed combustors. This system uses agricultural waste as fuel source to produce heat energy as an alternative to power rural community for light load applications. Test results recorded high flue gas and bed temperatures of over 300°C and 850°C respectively, suitable for rural application including grain drying and water boiling. Rozainee *et al.*

(2013) the purpose of their study was to investigate the effect of bed height on the quality of rice husk ash in a 210-mm diameter pilot scale fluidised bed combustor. The degree of rice husk burning in the fluidised bed could be deduced from the temperature of the combustor and the particle size of the resulting ash. The turbulence in the bed would breakdown the char skeleton of the rice husk into finer size. From this study, the bed height of 0.5D*c* was found to give the lowest residual carbon content in the ash (1.9%) and the highest bed temperature (670°C).

Lately, a few works from literature have been on boiler utilizing fuel oil for viable purposes and fluidised bed boiler. However, the issue is presently to harnessed agricultural waste as substitute to fuel oil in fluidised boiler for steam generation with the end goal of power generation. The inspiration for this study is to generate steam energy utilizing suitable waste-to-energy technologies.

In Kaduna state of Nigeria, production estimates for rice and maize were 364,170 MT and 1,027,790 MT respectively (NAERLS and NFRA, 2009). This shows enough potential of biomass waste to generate minimum of 90 MW of electricity. Shika community of Zaria Nigeria, generates about 3400 tonnes of waste annually, which is capable of producing a minimum of 1.9MJ/s of steam, sufficient for 200 kW of electricity from a power plant. In line with this, the present research analyses the performance characteristics of fluidised bed boiler by incineration of corncob into the system to generate steam at desired capacity, pressure and efficiency from the system and therefore aims atobtaining thermal energy from the developed fluidised bed boiler required forelectrification of rural communities not connected to national grid.

MATERIAL AND METHODS

Description of the Fluidised Bed Boiler

The fluidised bed boiler consists of the fluidised bed combustion chamber, steam drum, steam trap, steam tap, down-comer tubes, riser tubes, and frame support (See Figure 1).The combustion chamber provides conversion of chemical energy of fuel (corncob) to heat energy which in turn, was transferred to the heat absorbing surface of the boiler. Air for the supply of oxygen and buoyant force was supplied by a centrifugal blower, which passes through a perforated distributor plate, and then a bed of fuel particles of wide size distribution. The working fluid, which is water within the steam drum passes through the down comer tube to be heated within the combustion chamber and wet steam being generated returned to the steam drum through the riser tube being connected to the down comer within the combustion chamber. Subsequently, the wet steam generated passes through the superheater tube to be reheated within the combustion chamber for dry steam to be collected through the release valve.

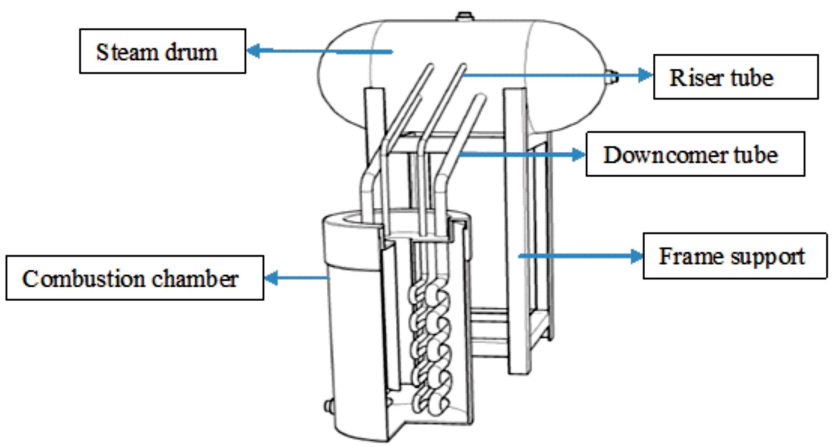

Figure 1: Developed fluidised bed boiler

Design Consideration and Equipment

The parameters considered for the design, fabrication, and experimental procedure of the developed fluidised bed boiler for steam energy generation are shown in Table 1.

Table 1: Design consideration

Parameters	Specifications	Equipment
Steam temperature	120^{o}C to 180^{o}C	Kane – May, 340 digital thermometers with thermocouple wire props (-50 to 1300^{o}C)
Steam pressure	2 bar to 5 bar	Maximator air filled pressure gauge (0 – 10 bar)
Steam capacity	2 kg/h to 10 kg/h	-
Calorific value of corncob	18.50 MJ/kg to 24.50 MJ/kg	-
Bed material	250 µm Fine sand	Mesh sieve of 250 µm
Bed height	27 mm, 47 mm and 77 mm	Vernier caliper

Design Analysis and Calculation

Design of the steam drum

The design of this component must be strong enough to contain steam or hot water that is generated and must able to mechanically hold the boiler tubes as they expand and contract with changes in temperature. Hence, its volume is of importance and is written as:

$$V_{dru} = A_{dru} \times L_{dru} \quad (1)$$

where, A_{dru} = Cross sectional area of the drum (m^2)
L_{dru} = Length of the drum (m)

Internal designed pressure of a boiler

The design pressure higher than operating pressure with 10% or more satisfies the requirement of boiler design, this pressure is based on the nominal thickness. The internal design pressure is given by (Ohijeagbon *et al.,* 2013).

$$P_d = \frac{\sigma_u \times t}{R_i \times f_s} \quad (2)$$

where, P_d = Internal design pressure on inside of drum or shell (N/m^2)
σ_u = Ultimate strength of plate (N/m^2)
t = Thickness of plate (m)
R_i = Internal radius of drum (m)
f_s = Factor of safety (ultimate strength divided by allowable working stress)
Tensile stress, σ_{ut} = 385 MN/m^2
Compressive stress, σ_{uc} = 665 MN/m^2
Shear stress, τ = 308 MN/m

Design of the steam tube

Materials which can withstand high temperature and resistance to corrosion such as galvanized steel materials were selected to form tubes.

$$V_{st} = A_{st} \times L_{st} \quad (3)$$

where, A_{st} = Cross sectional area of the tube (m^2)
L_{st} = Length of the drum (m)

Design height of the combustion chamber

This is given by the ratio of volume to combustion chamber area of the boiler.

$$H_{com} = \frac{V_{com}}{A_{com}} \quad (4)$$

where, H_{com}= Height of the combustion chamber (m)
V_{com} = Volume of the combustion chamber (m^3)
A_{com} = Cross sectional area of the combustion chamber (m^2)

Minimum wall thickness of tubes and drum

The minimum required wall thickness of a boiler is a value beyond which the boiler wall cannot be easily damage by the operation pressure in a boiler. The formula is given as (Ohijeagbon *et al*., 2013).

$$t_w = \frac{P_d \times R_i}{\sigma \times \eta_E - 0.6P_d} \quad (5)$$

where, σ = Allowable working stress of the material (N/m^2)
t_w = Minimum wall thickness (m)
η_E = Ligament efficiency of the welded joint

Therefore, the minimum wall thickness of the tubes is given as:

$$t_{w\,tubes} = \frac{P_d \times r_i}{2 \times \sigma \times \eta_E + 0.8P_d} + C \quad (6)$$

C = Corrosion allowance

Design of distributor thickness

The flow through plates can be described theoretically by a wide range of models, for perforated plates however, Hagen-Poiseuille's law can be used to describe the relationship between pressure drop across the distributor and superficial velocity. The thickness of the perforated hole is given as(Alekseev *et al*., 2016).

$$t_{dis} = \frac{\Delta P_d d_{or}^2}{32\mu U_{mf}} \quad (7)$$

where, ΔP_d = Pressure drop
t_{dis} = Distributor thickness
d_{or}^2 = Square of diameter of the orifice

Design of orifice

The aperture at which steam flows through the stop valve is an important parameter in boiler tube design, professionalism was applied in threading to avoid puncture. According to (Werther and Karri, 2003), the orifice velocity can be obtained from the orifice equation given below as:

$$U_{or} = C_d \sqrt{\frac{2\Delta P_d}{\rho_g}} \quad (8)$$

where, C_d = Coefficient of discharge
U_{or} = Orifice velocity
ρ_g = Density of the gas (kg/m^3)

Design feed hopper

Biomass fuel was fed into the bed via a hopper which functions with the help of gravity. The absence of moving part makes it suitable for rural application, where routine maintenance may not be forthcoming. Hence, its area is of importance to accumulate the size of fuel and is written as:

$$A_{fh} = L_{fh} \times B_{fh} \times H_{fh} \quad (9)$$

where, A_{fh} = Area of feed hopper (m^2)
L_{fh}= Length of feed hopper (m)
B_{fh}= Breadth of feed hopper (m)
H_{fh}= Height of feed hopper (m)

Calorific value of corncob as fuel

The fuel has a significant effect on the design and operation of fluidised bed combustion boiler. Fuels with higher reactivity have greater combustion efficiency. Previous studies show that the amount of combustible losses in the fly ash is inversely proportional to the heating value of the fuel (Basu *et al*., 2011). Corncob with calorific value of 5841.22 kcal/kg (24.44 MJ/kg) was considered in this design (Balogun *et al*., 2016). Hence, the heat energy liberated by complete combustion of a unit mass of fuel can be approximated from Dulong's formula given as (Rajput, 2010).

$$HCV = 33{,}800C + 144{,}000\left(H - \frac{O}{8}\right) + 9270S \qquad (10)$$
$$LCV = HCV - 9H \times 2{,}466 \qquad (11)$$

where, HCV = Higher calorific value (kJ/kg)
LCV = Lower calorific value (kJ/kg)

Stoichiometric air-fuel ratio

Adequate supply of air is essential for the complete combustion and for obtaining maximum amount of heat from fuel. The amount of oxygen required for 1 kg of fuel maybe calculated from the chemical analysis of the fuel. The composition of raw corncob waste by percentage weight is as follows; 42.0% C, 6.7% H_2 ,1.5% N_2 and 48.1% O_2 (Lu and Chen, 2013).

Steam capacity

Depending on the size of turbine choosing for power generation, the amount of steam produced from the boiler should be able to run the turbine sufficiently. Steam condition extraction pressure of 4.0 to 7.7 bar is sufficient enough to generate 20 MW of power (Heppenstall, 1998; Karri, 2012)

Table 2: Summary of the design calculation

Initial Data	**Calculations**	**Results and Remarks**
Type of boiler	Bubbling fluidised bed boiler	
Design of steam drum		
$D_i = 0.6\,m$ $L_{dru} = 1\,m$	Volume of steam drum or boiler shell $\frac{\pi}{4} \times 0.6^2 \times 1 = 0.283\,m^3$	For this design specification, the volume of steam drum was calculated as V_{dru}= 0.283 m^3
Internal designed pressure of the boiler		
σ_{ut} = 385 MN/m^2 t = 0.003 m R_i = 0.3 m f_s = 5	$P_d = \frac{\sigma_u \times t}{R_i \times f_s} = \frac{385 \times 0.003}{0.3 \times 5}$ $P_d = 0.77\,MN/m^2 \cong 770{,}000\,N/m^2$ Hence, $P_d = 7.7\,bar$	The design pressure was calculated as: $P_d = 7.7\,bar$
Design of steam tubes		
$d_i = 0.0127\,m$ L_{st} = 3 m	Volume of tube $\frac{\pi}{4} \times 0.0127^2 \times 3 = 0.038\,m^3$	Babcock and Wilcox, stated that the minimum and maximum allowable tube diameter are 0.01 m and 0.0635 m. Therefore, the volume of the steam tube was calculated as V_{st} = 0.038 m^3
Design of combustion chamber		
$D_i = 0.5\,m$ H_{com}= 1 m	Volume of combustion chamber $V_{com} = \frac{\pi}{4} \times 0.5^2 \times 1 = 0.196\,m^3$	For this design specification, the volume of combustion chamber was calculated as V_{com}= 0.196 m^3
Types of feed	Agricultural waste (chipped corncob and charcoal)	The corncob was from Shika community, Zaria.
Bed material	Sand	Sand material of 250 µm and particle density of 2.659 *g/cm^3* was used with bed height of 0.027 *m*, 0.047 *m* and 0.77 *m* were adopted.
Design of minimum wall thickness		
For the Drum $P_d = 0.77\,MN/m^2$ D_i = 0.6 m η_E = 1 $\sigma_{t1} = 77\,MN/m^2$ Also, for the tube $d_i = 0.0127\,m$ $C = 3$	$t_w = \frac{P_d \times R_i}{\sigma \times \eta_E - 0.6P_d} = \frac{0.77 \times 0.3}{77 \times 1 - 0.6 \times 0.77}$ $t_w = 3.0181 \times 10^{-3}\,m$ $t_w = 3.018\,mm$ $t_{w\,tubes} = \frac{P_d \times r_i}{2 \times \sigma \times \eta_E + 0.8P_d} + C$ $t_{w\,tubes} = \frac{0.77 \times 0.00635}{2 \times 77 \times 1 + 0.8 \times 0.77} + 3$ $t_{w\,tubes} = 3.0312\,mm$	$t_w = 3.018\,mm$ Take $t_w = 3.0\,mm$ $t_{w\,tubes} = 3.0312\,mm$ Take $t_{w\,tubes} = 3.0\,mm$
Design of feed hopper		
$L_{fh} = 0.2\,m$ $B_{fh} = 0.5\,m$ $H_{fh} = 0.7\,m$	$A_{fh} = L_{fh} \times B_{fh} \times H_{fh}$ $A_{fh} = 0.2 \times 0.5 \times 0.7$ $A_{fh} = 0.07\,m$ $A_{fh} = 70\,mm$	For this design specification, the calculated desired feed hopper of the boiler was $A_{fh} = 70\,mm$
Velocity of fluids in tubes, pipes and drum		
From steam table; v = 0.3427 m^3/kg of water @ 155 ^oC M_w = 48 kg/hr	$V = 0.05 \times M_w \times \frac{v}{D_i^2} = 0.05 \times 48 \times \frac{0.3427}{0.6^2}$ $V = 2.284\,m/s$	For this design specification, the velocity of fluids in the steam drum is calculated to be $V = 2.284\,m/s$
Design of frame support		
L = 0.6 m B = 0.3 m H = 1.5 m	Area of frame support $A_{fs} = 0.6 \times 0.3 \times 1.5 = 0.270\,m$	$A_{fs} = 0.270\,m$

Material Selection

Table 3 shows the materials selected for the fabrication of the fluidised bed boiler, which were selected based on their physical and mechanical properties, and their availability.

Table 3: Detailed selected materials and fabrication

Component	Materials	Fabrication process
Combustion chamber	Mild steel sheet	- Mark out 1000 mm x ϕ500 mm on the 3 mm thick flat sheet. - Roll the 1000 mm x ϕ500 mm into a hollow cylinder. - Weld the free ends together with gas welding to form hollow cylinder. - Then coat with aluminum paint.
Steam drum	Galvanized steel sheet	- Mark out 1000 mm x ϕ600 mm on the 3 mm thick flat sheet. - Roll the 1000 mm x ϕ600 mm into a hollow cylinder. - Weld the free ends together with gas welding to form hollow cylinder. - Drill 7 holes of ϕ19.05 mm, 5 of it for the tubes, 1 for blow down cock and 1pressure gauge on top.
Distributor plate	Mild steel plate	- Mark out 120 mm x 500 mm on the 2 mm thick flat sheet. - Make perforations evenly distributed over the plate to be of 3 mm in diameter (Orifice diameter) and 700 in number. - Weld the end round to combustion chamber with gas welding at height of 130 mm from the plenum chamber.
Hooper	Mild steel plate	- Mark out 200 mm x 500 mm x 700 mm on the 2 mm thick flat sheet. - Make it to form a funnel shape like by forging process. - Weld the 200 mm end to combustion chamber with gas welding at height of 620 mm from the distributor plate. - Then coat with aluminum paint.
Downcomer tube	Galvanized steel pipe	- 3 m long galvanized was bought of ϕ (¾)" pipe. - Cut the pipe into half and then bend it into 3" curvature, which is 76.2mm. - 2 Downcomer was achieved in total with respect to this design specification. - Weld the downcomer pipe to the front of the steam drum and to the combustion chamber. - Allowing the bottom bend to suspend at a height of 0.3 m just above the distributor plate. - Making threading at the top of the pipe in order to be joined from steam drum to combustion chamber with a union connector.
Riser tube	Galvanized tube	- 3 m long galvanized was bought of ϕ (1/2)" pipe. - Cut the pipe into half and then bend it into 3" curvature, which is 76.2 mm. - 2 Riser was achieved in total with respect to this design specification. - Weld the riser tube to the front of the steam drum and to the combustion chamber. - Allowing the bottom bend to suspend at a height of 0.3 m just above the distributor plate. - Making threading at the top of the pipe in order to be joined from steam drum to combustion chamber with a union connector.
Super heater tube	Galvanized steel pipe	- 3 m long galvanized was bought of ϕ (1/2)" pipe. - Cut the pipe into half and then bend it into 3" curvature, which is 76.2 mm. - 1 single super heater was used in this work with respect to this design specification. - Weld the super heater tube to the front of the steam drum and to the combustion chamber to divide the set of riser tube and downcomer tube and a non-return valve at 0.0762 m just after the stem drum. - Allowing the bottom bend to suspend at a height of 0.3m just above the distributor plate. - Making threading at the top of the pipe in order to be joined from steam drum to combustion chamber with a union connector.
Frame support	2" x 2" angle iron	- Cut the full length of the angular iron into 2 equal parts. - Mark out 1500 mm into 4 places for the stand of the frames. In addition, cut out 300 mm out for brazing of the legs. - Weld the brazing legs to the main stand at 150 mm from the bottom and 250 mm from the top by arch welding.

Firing/Ignition Procedure

The system was assembled outside the boiler room, mechanical engineering departmental workshop, ABU Zaria. The water used throughout the running was sourced from the tap water running from Ahmadu Bello University water board. The bed material (sand) was prepared by removing larger particles which can potentially affect the quality of fluidisation using a sieve.

Fine sand of 250 µm was feed evenly onto the distributor plate through the manhole opening up to a desired static bed height of 77 mm, 47 mm and 27 mm respectively. An air blower with capacity of 0.7 MPa rated 0.28 kW, 60Hz was used to provide the buoyant forces for fluidization and in addition provides the oxygen for combustion.

Some charcoal in small pieces was feed onto the bed for pre-heating of the system. Conversely, 1 kg of the corncob waste samples from Shika community, Zaria as the raw biomass fuel was cut into pieces with 3 ± 0.5 mm in diameter and 10 ± 0.5 mm in length to equalize their sizes and was feed in at 10 minutes interval through the hopper.

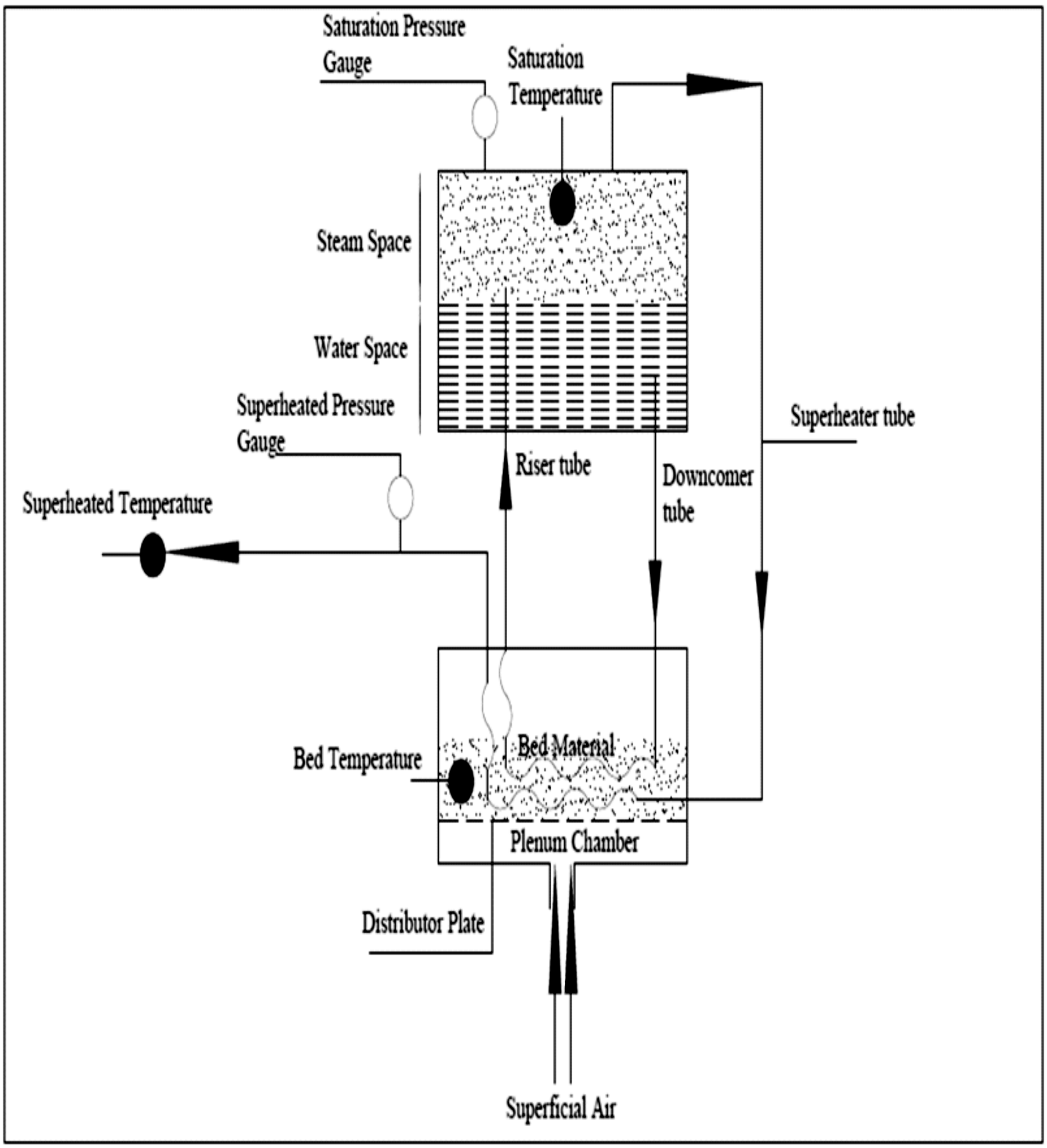

Figure 2: Flow diagram of the developed boiler

RESULTS AND DISCUSSION

Superheated Temperature of Steam at Superheater Tube

The temperatures of the steam at the super heater tube with respect time were taken at 5 minutes interval. Figure 3 depicts the superheated temperatures of the three bed heights. It can be deduced from the Fig., that at 30 minutes, superheated steam was obtained from the 27 mm bed height and it started attainting stability at 35 minutes from temperature ramp of 163^{o}C up to 60 minutes at 168^{o}C. Additionally, the bed height of 77 mm attains stability at 50 minutes at 140^{o}C. The stability of the superheated steam of 47 mm bed height was attained at 35 minutes up to 50 minutes at 147 ^{o}C and there was a slight drop in temperature to 140^{o}C and this can be said to be attributed to loss of heat due to release of the steam through steam outlet valve.

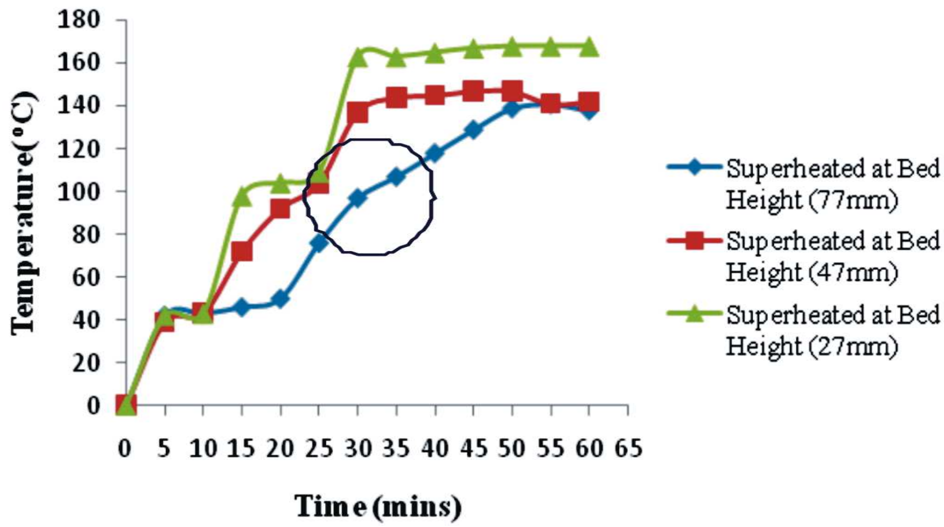

Figure 3: Variation of superheated temperature of steam and bed height as a function of time

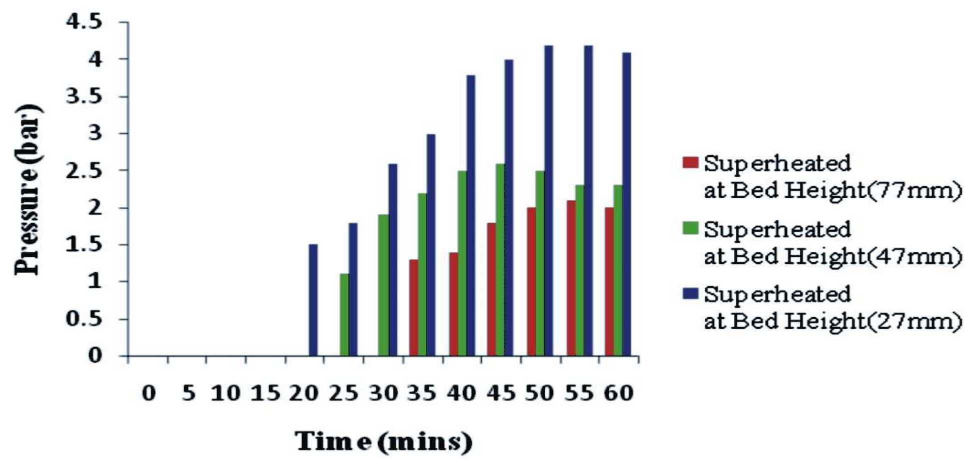

Figure 4: Superheated pressure of steam and bed height as a function of time

Superheated Pressure of Steam at Super Heater Tube

Superheated pressures of the steam at the super heater tube at 5 minutes interval were taken as shown in Figure 4. It was observed from the Figure, that at the beginning of the experiment there were no traces of superheated pressure in super heater tube not until after the 20 minutes for the bed height of 27 mm, 25 minutes for bed height of 47 mm and 35 minutes for bed height 77 mm. As shown from Figure 4, the maximum superheated pressure obtained were 2.1 bar at 55 minutes for bed height of 77 mm, 2.6 bar was also obtained from bed height of 47 mm at 45 minutes. Towards the specified one-hour (1 hour.) end time of the experiment, 4.2 bars was obtained from bed height of 27 mm between 45 to 55 minutes.

Bed Temperature

Figure 5 shows the bed temperature variation with time. The initially measured temperature of the bed at the onset of fluidization was 31^{o}C for bed height of 77 mm, 40^{o}C for bed height of 47 mm and 42^{o}C for bed height of 27 mm. The bed temperature rises proportionally with time and at 20 minutes, there was a significant increase in bed temperature for each of the bed height this can be said to be attributed to stable supply of fluidising velocity for combustion and there was a decrease after 50 minutes and this is attributed to stoppage of fuel feeding. This result can be supported with the study of Varol *et al.* (2014). Hence, the maximum bed temperature obtained throughout the experiment was 724^{o}C at 40 minutes for the bed height of 27 mm and this is incline with bed temperature of a fluidised bed boiler.

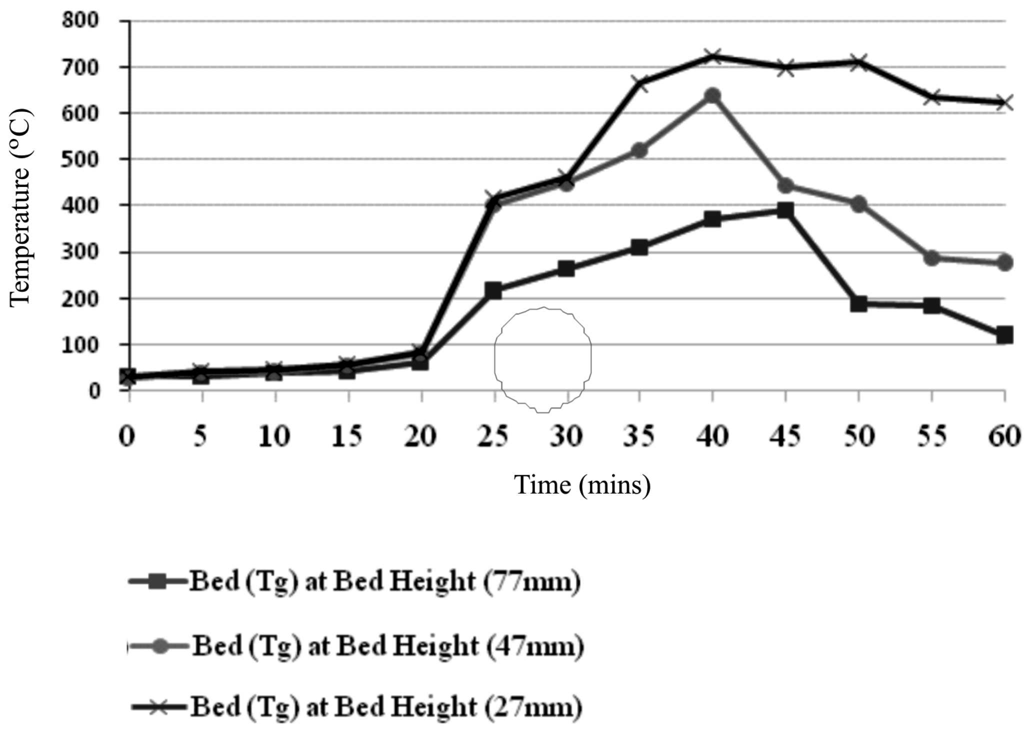

Figure 5: Bed temperature profile as a function of time

Amount of Steam Generated

Figure 6 presents the amount of steam generated in kg/h. The Figure revealed that 5.6 kg/h of steam was build up from bed height of 77 mm within an hour as the stipulated running time of the experiment. Steam capacity of 6 kg/h was achieved from 47 mm and 6.6 kg/h as maximum capacity of steam was achieved from the bed height of 27 mm and this is capable to run a medium capacity steam turbine, sterilization of medical equipment.

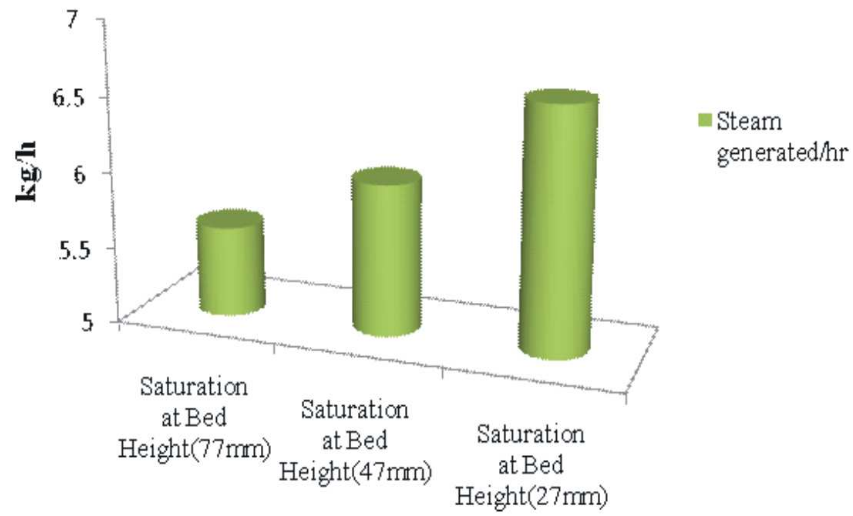

Figure 6: Rate of steam generation for different bed height

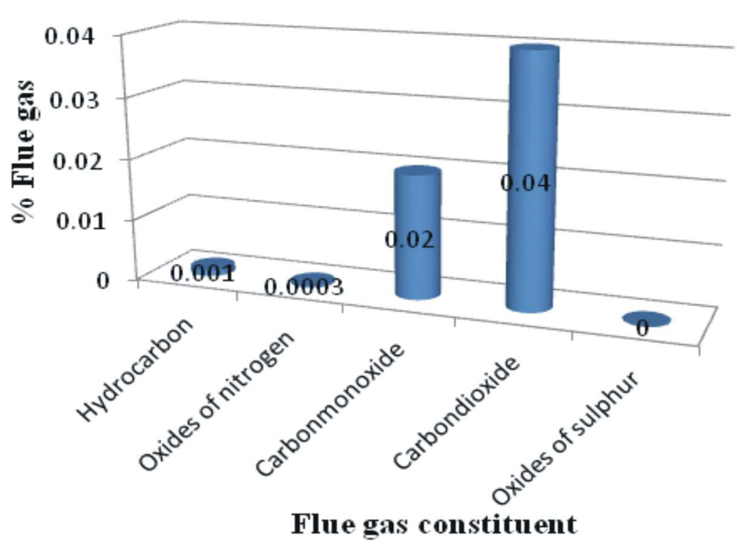

Figure 7: Percentage composition of the flue gas constituent

Analysis of the Flue Gas Emission

The exhaust flue gas of the developed boiler is presented below after being analyzed with a flue gas analyzer. Figure 7 presents the exhaust emission in their percentages. As seen from the Figure 7, the harmful emissions were found to be low to their barest minimum and this is attributed to granular material which is crystalline in nature that absorbs the harmful gas within the combustion chamber. This study corroborates with the finding of Thenmozhi and Sivakumar, (2013). The oxides of Sulphur were found to be zero and this can be said to be attributed to low contents of Sulphur in biomass fuel.

CONCLUSIONS

Fluidized bed technology is proving to be the most practical option for biomass conversion. Hence, from the experimental result it can be concluded that that the bed height of 27 mm gives a better fluidization result. Stability in the superheated temperature of steam was observed at 30 minutes up to 60 minutes with corresponding temperature of 163^oC to 168^oC. More so, the steam generated is capable for power generation with selected Fuji Electric Medium Capacity Steam Turbine "FET Series". Furthermore, flue gases at over 300°C have been generated by the system, thereby providing alternative ways for drying and other low thermal applications. Char produced from maize cobs combustion could be converted to form charcoal briquettes for use in advanced wood stoves and improving the total economic output of the fluidised bed combustor.

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