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DESIGN OF A 60MW CFB GASIFICATION SYSTEM (CGAS) FOR UGANDA-UTILISING RICE HUSKS AS IN PUT FUEL

FREDRICK AMANYIRE [1], DAVIS BARIHO BAGAMUHUNDA [2]

[1] Department of Biosystems Engineering Gulu University, P.O. BOX 166 Gulu (Uganda) <afredie2005@yahoo.com>
[2] Uganda Industrial Research Institute, Technology Development Centre, P.O. BOX 7086 Kampala (Uganda) <bagsondavis@yahoo.co.uk>

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ABSTRACT Biomass resources are potentially the World's largest and most sustainable renewable energy resource. In Uganda Biomass comprises over 95% of the total energy supply. Agricultural residues are a major source of energy and can be effectively harnessed by converting them into producer gas in suitably designed biomass gasifiers. Over 90% of the Ugandan population has no access to electricity due to limited and unreliable electricity produced in the country and this has resulted in high poverty levels. To generate a system for effective utilization of agricultural wastes for energy production, a circulating fluidized bed (CFB) gasification system was designed with fuel input as rice husks for a power output of 60MW. The gasification system was designed using ERGUN CFB software with the available theoretical and experimental data. The design was divided into four parts: reactor subsystem, air distribution plate, cyclone, air inlet and fuel feeding systems. The designed gasifier has an overall reactor height of 10m, fuel flow rate of 8.1kg/s, inlet air flow rate of 11m^3/s, fluidization velocity of 0.9m/s, pressure drop in the bed of 1.5kPa, 25.2m/s cyclone inlet gas velocity, about 99% cyclone efficiency, less than 1kPa pressure drop in cyclone, gas flow rate of 41.2kg/s and effective cold gas efficiency of 50%. Under the mentioned design conditions, the gasifier can be used for effective power generation of 60MW from locally available and environmentally friendly energy resources.

Keywords: Circulating Fluidized Bed (CFB), Gasifier, Rice husks, Biomass

INTRODUCTION

Most of the energy consumed in the world is from non-renewable energy sources. Increase in energy consumption has resulted into increase in non-renewable energy and this has resulted into diverse environmental effects in the world. However these effects can be minimised by turning to renewable energy sources like biomass.

The quality of biomass fuel varies with the season and region. Moisture may be high, fuel handling and feeding can be more demanding, and there are common problems of fouling, formation of deposits, slagging, and super heater corrosion in case of biomass-fired boilers. With respect to problems addressed above, the most common technologies for industrial combustion of solid biomass fuels are: bubbling fluidized bed boilers/gasifiers (BFB), circulating fluidized bed boilers/gasifiers (CFB) and grate fired boilers.

In the last ten years, rice production in Uganda has grown by around 400%. Currently the country produces about 500,000 tonnes per year and this may exponentially increase given the campaign of rice growing that the government has emphasized. This will lead to a considerable quantity of rice husks which can be used in CFB gasisfiers and hence solving the energy problem which has curtailed the country of recent.

Fluidized Bed Combustion (FBC) offers the opportunity to burn a wide variety of fuels that are deemed to be of poor quality for use in conventional firing systems. Fuels which contain high concentration of ash, sulphur, and nitrogen can be burned efficiently. The main advantages of FBC include: fuel flexibility, ability to burn low-grade fuels, low NO_X production and in-situ capture of SOx.

Fluidization refers to the condition in which materials are given a "fluid" behaviour. In the case of FBC air is passed upwards through a bed of solid particles in order to separate them. At low gas flows, the particles remain in contact with other solids and tend to resist the movement. This is known as fixed bed combustion. If the gas flow is increased a point is reached when the particles are separated from each other and the bed becomes fluidized. CFB conditions are generally reached at velocities higher than 3 m/s with mean particle size smaller than 500µm. These conditions lead to an excellent mixing and gas-solid contact with high performance in terms of combustion efficiency and low emission levels.

METHODOLOGY The CFB gasifier was designed basing on Rice Husks as the fuel and power output of 60 MW. The operating conditions of the gasisier considered were 850^oC and 101325 Pa. Air was considered as the gasifying agent and Sand as the inert material. The available data was used in ERGUN design software for CFB equipment.

Reactor subsystem A design for the overall height of the reaction chamber, minimum fluidisation velocity, terminal velocity, and fluidisation velocity was done.

The physical properties of fuel and inert material (sand) used in the design are shown in table 1.

Table 1: Physical properties of sand, rice husks, and air

Properties	**Value**		
	Sand	**Rice husks**	**Air**
Mean particle size (d_p) µm	60	856	NA
Density of particle (ρ_p) kg/m^3	2600	389	NA
Porosity: ε	0.46	0.64	NA
Sphericity: Φ	0.78	0.49	NA
Density of fluid (ρ_f) kg/m^3	NA	NA	0.314
Viscosity of fluid (μ) Ns/m^2	NA	NA	$4.49*10^{-5}$

NA – Not Applicable

The Minimum fluidization velocity (U_{mf}) and Terminal velocity (U_t) of rice husks were calculated using equations 1 and 2 respectively:

$$U_{mf} = \frac{d_p^{\ 2}.(\rho_p - \rho_f).g}{150 \cdot \mu} \times \frac{\varepsilon^2 \cdot \phi^2}{1-\varepsilon} \tag{1}$$

$$U_t = d_p \cdot \left[\frac{4 \cdot (\rho_p - \rho_f)^2 . g^2}{225 \cdot \rho_f \cdot \mu} \right]^{\frac{1}{3}} \tag{2}$$

Fluidization velocity (U_f) and overall height (H_t) of the reaction chamber were calculated using equations 3 and 5 respectively. The ratio H/H_{mf} was assumed to be 1.3 according to equation 4.

$$\frac{H}{H_{mf}} = 1 + \frac{10.978 \cdot (U_f - U_{mf})^{0.738} \cdot \rho_p^{\ 0.376} \cdot d_p^{\ 1006}}{U_{mf}^{\ 0.967} \cdot \rho_f^{\ 0.126}} \tag{3}$$

$$1.2 < \frac{H}{H_{mf}} < 1.4 \tag{4}$$

$$Ht = TDH + H \tag{5}$$

The expanded bed height H was assumed to be twice the internal diameter of the reaction chamber. The threshold disengaging height (TDH) was calculated by use of internal diameter (d_i=1.67m), an assumed fluidization velocity (U_f=0.9m/s), and graphical correlations in figure 1.

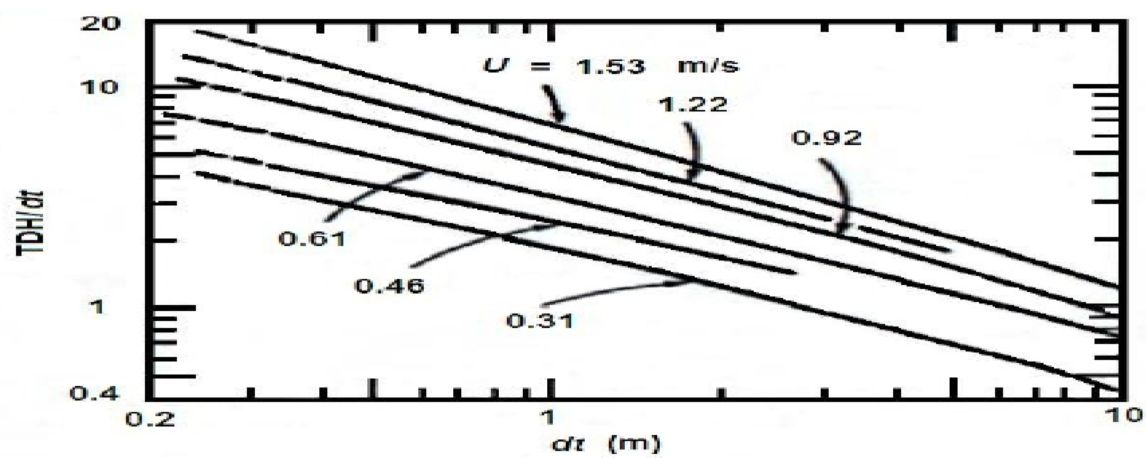

Figure 1: Zens and Weil correlations to TDH calculation

Air distribution plate For the grid design, tuyeres section was considered. This is because it consists of a plate with vertical nozzles and lateral perforations through which air passes and is distributed uniformly into the reactor. It is also convenient at high temperatures and reduces backflow of bed material towards the plenum. The input data is shown in table 2.

Table 2: Specifications for tuyeres section

Tuyeres section	
Riser diameter of Tuyeres (m)	0.02
Number of tuyeres per m^2	150
Nozzles diameter (m)	0.02
Number of jets per tuyere	2

Cyclone design The cyclone designed was based on cyclone inlet gas velocity of about 25m/s, pressure drop of less than 2.5kPa and efficiency of more than 85%. The cyclone diameter (Dc) which could meet the above conditions was 1.87m. The other dimensions of the cyclone depend on the cyclone diameter as shown in figure 2. The other input data considered included inlet air flow rate (39630m^3/h), density and viscosity of air, density and mean particle size of particle.

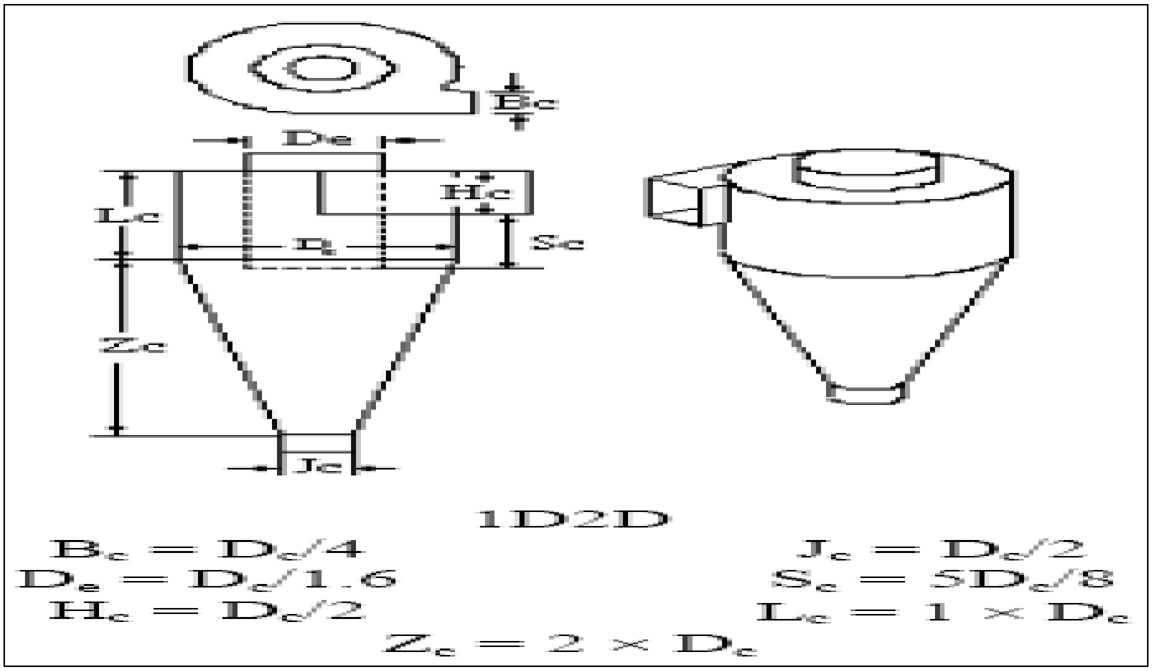

Figure 2: Schematic of 1D2D cyclone design

Fuel feeding and air inlet system design The design was based on 60 MW power output, Cold Gas efficiency of 50%, and fuel elementary analysis in table 3. The lower heating value of 14.89MJ/kg was considered and fuel mass flow rate was calculated using equation 6. The stoichiometric air fuel ratio (m_n^3 of air/kg fuel) was obtained by use of table 3. Considering equivalence ratio Φ= 0.4 for gasification, the real air fuel ratio ($m_n^3$of air/kg fuel) was obtained using equation 7. The inlet air flow (m_n^3/h) was got using equation 8.

$$\eta_{CG} = \frac{LHV_{gas} \cdot \dot{V}_{gas}}{LHV_{fuel} \cdot m_{fuel}} \cdot 100\% = \frac{PowerOutput}{FuelPower} \cdot 100\% \qquad (6)$$

$$\Phi = \frac{\text{Re}\, alairfuelratio}{Stoichiometricairfuelratio} \quad (7)$$

$$InletAirflow = \text{Re}\, alairfuelratio * fuelmassflow * 3600 \quad (8)$$

Table 3: Data used in calculation of fuel flow rate and air flow rate

Parameter	Value
The amount of fuel mass kg/s	8.06
The fuel elementary analysis (C,H,N,S,O, and Ash)	
C (%)	38.0
H (%)	4.4
N (%)	1.0
S (%)	0.1
O (%)	35.5
Ash (%)	21.0
Amount of air to be put into the gasifier	
$Ot = \frac{1}{100}(\frac{c}{12} + \frac{h}{4} + \frac{s}{32} - \frac{o}{32})$	0.0316 kmol O_2 / kg fuel
$= \frac{32}{100}(\frac{c}{12} + \frac{h}{4} + \frac{s}{32} - \frac{o}{32})$	1.0113 kg O_2 / kg fuel
$= \frac{22,7}{100}(\frac{c}{12} + \frac{h}{4} + \frac{s}{32} - \frac{o}{32})$	0.7174 m_n^3 O2 / kg fuel
$lt = \frac{1+3.76}{100}(\frac{c}{12} + \frac{h}{4} + \frac{s}{32} - \frac{o}{32})$	0.1504 kmol air / kg fuel
$= \frac{32+3.76*28}{100}(\frac{c}{12} + \frac{h}{4} + \frac{s}{32} - \frac{o}{32})$	4.3386 kg air / kg fuel
$= \frac{4.76*22,7}{100}(\frac{c}{12} + \frac{h}{4} + \frac{s}{32} - \frac{o}{32})$	3.4149 m_n^3 / kg fuel
Real air-fuel relation	**1.3660** m_n^3 / kg fuel
Inlet air flow	**39630.1928 m_n^3/h**

RESULTS AND DISCUSSION

Reactor subsystem The designed overall height for the reaction chamber, minimum fluidization velocity, terminal velocity, fluidization velocity for sand and rice husks are shown in table 4. Figure 3 shows the operating region of the designed gasifier.

Table 4: Parameters for the designed reactor subsystem

Parameter	Material	Value
Fluidization velocity (m/s)	Sand	0.0144
	Rice husks	0.2332
	Selected value for design	0.9
Overall height of the reaction chamber (m)	Calculated value	9.2086
	Selected value	10.0
Minimum fluidization velocity (m/s)	Sand	$1.2378*10^{-3}$
	Rice husks	$7.2047*10^{-2}$
Terminal velocity (m/s)	Sand	$1.1366*10^{-1}$
	Rice husks	2.2521

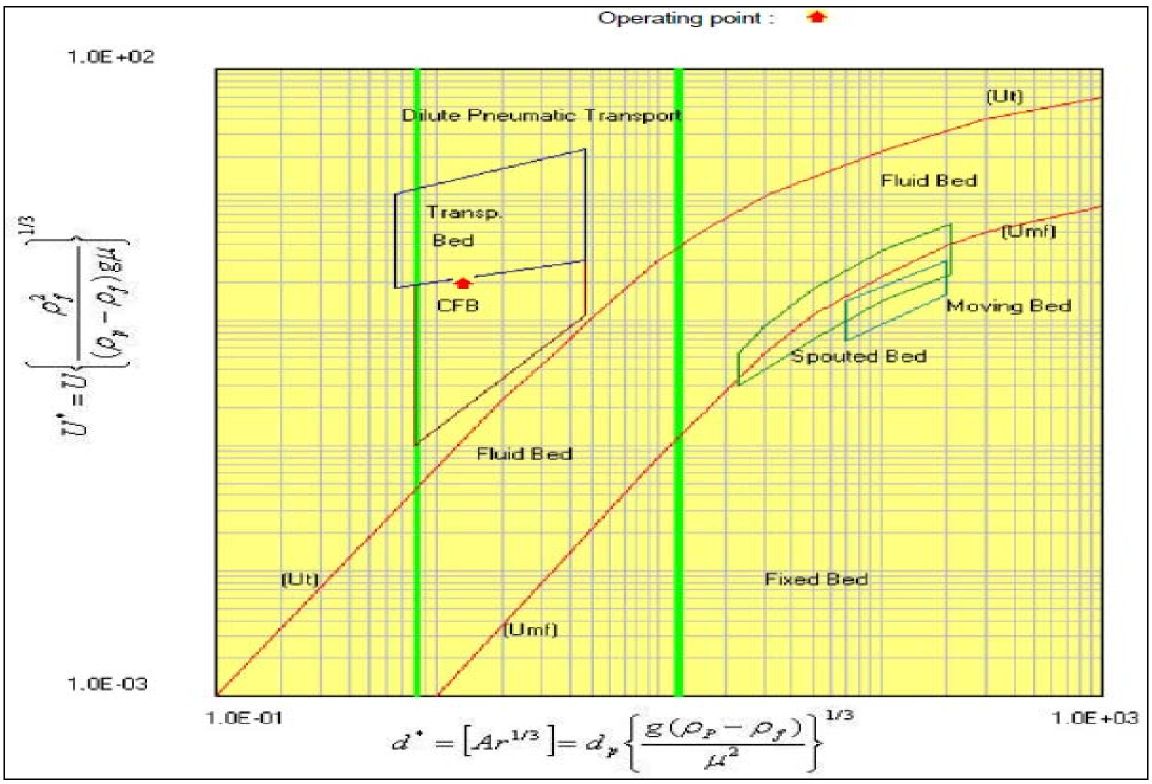

Figure 3: Operating region for the designed gasifier

Air distribution plate Results of main parameters of the designed air distribution plate are shown in table 5.

Table 5: Designed air distribution plate parameters

Parameter	Value
Pressure drop in the bed (kPa)	1.544
Tuyer orifice diameter (m)	0.006
Pressure drop in the distributer (kPa)	0.281
Tuyer internal diameter (m)	0.020
Air velocity for the orifice (m/s)	53.080
Total Number of tuyers	330
Tuyer height (m)	0.010

Cyclone designed The number of effective turns, cyclone inlet gas velocity, pressure drop, efficiency, and dimensions of the cyclone designed are shown in table 6. Since the efficiency is greater than 85%, pressure drop is less than 2.5kPa and the inlet velocity is about 25m/s, then the cyclone can effectively be used in the separation.

Table 6: Designed cyclone dimensions and parameters

Parameter	Value
Cyclone diameter (m)	1.870
Cyclone gas exit diameter (m)	1.169
Cyclone body cylindrical height (m)	1.870
Cyclone total height (m)	5.610
Cyclone solids exit diameter (m)	0.935
Cyclone inlet gas velocity (m/s)	25.184
Pressure drop (kPa)	0.140
Cyclone Efficiency (%)	99.920
Number of Effective Turns	4

Fuel feeding and air inlet system From the elementary analysis of rice husks and calculation of the fuel flow and air flow in the methodology, opening area of the fuel and air was calculated (results in table 7). Operating velocity in the reaction chamber for air and fuel was considered to be 5m/s, porosity of 0.64 for rice husks, and fuel density of 389kg/m^3 was considered in the calculation. The opening area of the gas was determined from the cyclone dimensions.

Table 7: Opening areas for fuel, air, and gas

Parameter	Value
Fuel opening area (m^2)	0.006
Air opening area (m^2)	2.202
Air opening area (m^2)	1.073

CFB pressure chart The pressure at different crucial points of the gasifier is shown in figure 4. Since the siphon pressure drop is greater than the return leg pressure drop, the solids can effectively be circulated in the gasifier.

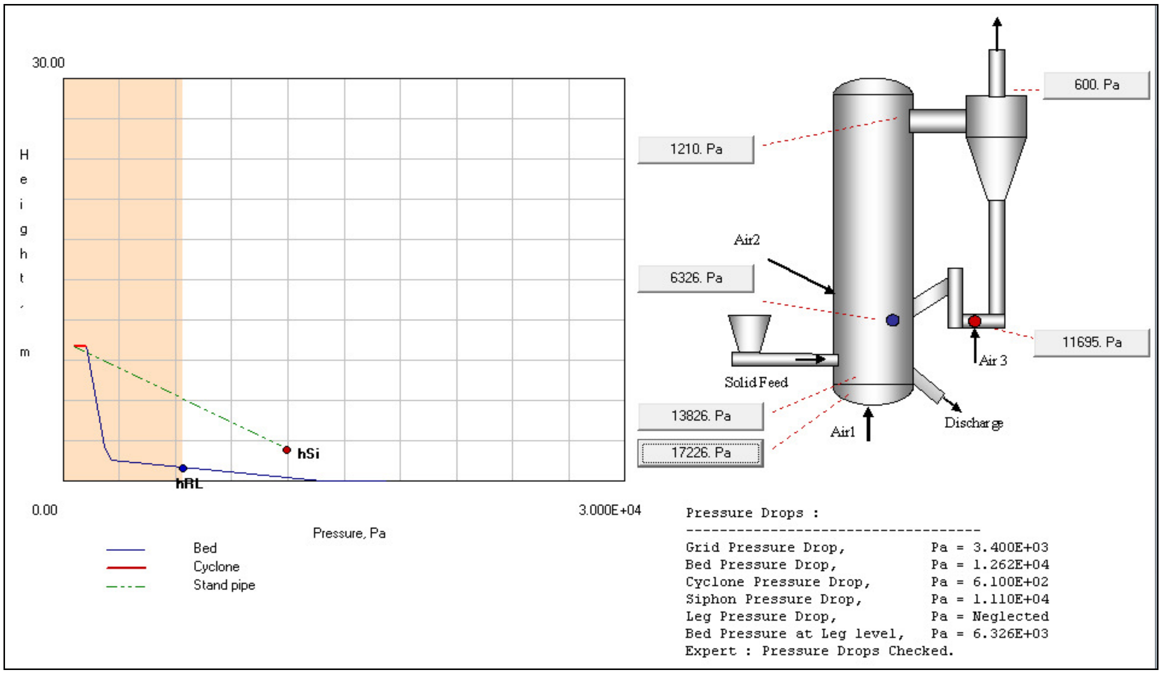

Figure 4: CFB pressure chart for the designed gasifier

CONCLUSION The CFB gasifier designed by use of Ergun software is able to deliver 60MW of power output and uses rice husks as fuel. The gasifying agent is air and the inert material is sand. Fuel flow is 8.06kg/s and requires inlet air flow of 11m^3/s. Flow rate of the gas is 41.39kg/s and solids circulating rate (SCR) is 98. The cyclone diameter is 1.87m, efficiency is 99.92% and pressure drop is 1.544kPa. The design cold gas efficiency of the gasifier is 50%. Therefore the designed gasifier can be sustainably used in power generation as well as energy production and hence tackling the energy problem in Uganda and also averting the global environmental impacts.

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