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Original Research Article

Theoretical and Experimental Studies of Rice Husk Gasification Using Air as Gasifying Agent in a Downdraft Gasifier

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ABSTRACT

Biomass gasification is a thermochemical process that converts biomass to a combination of gases known as syngas. It is considered to be a clean energy route and a way of reducing greenhouse gas emissions. Syngas has wide application in heating, power generation and synthesis of chemicals and liquid fuels. This paper reports a mathematical model formulation to predict rice husk gasification and experimental gasification of rice husk using air as gasifying agent. Theoretical rice husk gasification was done by inputting the composition of a characterized rice husk into set of mathematical equations derived using equilibrium approach and the resulting equations were solved using Newton Raphson method in MATLAB between temperatures of 500 and 1100 °C. Experimental rice husk gasification was conducted using a downdraft gasification system comprising of a gasifier as reactor, cyclone, filter, air blower and attached gas analyzer. Effect of varying air flow rates (6.4, 3.0 and 0.7 L/min) were studied; temperature, syngas composition and calorific value were monitored. The results of the model indicated an optimum temperature at 800 °C with syngas calorific value of 4.47 MJ/m^3. The best experimental syngas composition recorded was at 6.4 L/min air flow. Root mean square error value of 7.58 was calculated when the model developed was validated with the best results obtained from the experiment. Performance analysis shows that for experimental gasification, the highest carbon conversion efficiency and cold gas efficiency were achieved at the highest air flow rate (6.4 L/min) as 21.27 and 12.55% respectively.

1. INTRODUCTION

Access to sustainable, affordable and clean energy supply is a precursor for attaining and sustaining socio-economic development (McCollum et al., 2017). Currently about 90% of the world primary energy consumption is from fossil fuels (petroleum, gas and coal) (IEA, 2016). However, awareness about fossil fuel depletion, the continued growth of global energy consumption, energy security and environmental issues are factors that drive the search for alternative and renewable energy sources (Apergis and Danuletiu, 2014). One of the most promising renewable energy options is energy from biomass.

The energy in biomass can be converted to useful forms of energy through either thermochemical (combustion, pyrolysis and gasification) or biochemical (fermentation and digestion) processes (Caputo et al., 2005). Thermochemical conversion route can process any solid organic matter and the process is faster than biochemical conversion (Basu, 2010). Gasification is a thermochemical process in the presence of gasifying agent (air, oxygen or steam) that converts carbonaceous matter like biomass under partial oxidation condition into more valuable gaseous fuels or chemical feedstock (Basu, 2010). In developing countries, biomass is the major source of energy especially in rural areas, accounting for about 75% world consumption, but mostly their utilization is not through sustainable ways and is not environmentally friendly (Sahito, 2013).

The performance of biomass gasification is measured in terms of the quality of the syngas produced (composition and calorific value) and the amount of impurities generated such as tar (Molino et al., 2018). The quality is largely influenced by several factors which include proper design/gasifier configuration (fixed bed, fluidized bed, and entrained type gasifier), right choice of the operating or process parameters (gasifying agent, temperature, and equivalence ratio) and biomass type as well as size, shape, absolute/bulk density of the biomass (Sikarwar et al., 2016). Different gasifying agents are used in the gasification system. The commonly used ones are air, oxygen, and steam (Rivas, 2012). The amount of gasifying agent supplied to a gasification system is expressed as equivalence ratio (ER) for air/oxygen gasification, steam to biomass ratio (S/B) for steam gasification and gasifying ratio for steam–oxygen gasification (Basu, 2010).

In a fixed bed gasifier, when the gasifying agent is fed from the top with the biomass and syngas exiting from the bottom, it is term downdraft gasifier while if the gasifying agent is fed from the bottom moving counter currently with the biomass and the syngas exits from the top of the gasifier, it is called updraft. The carbonaceous material in a gasifier undergoes several different processes namely; drying, pyrolysis (devolatilization), combustion (oxidation), and gasification (reduction) processes (Bhavanam and Sastry, 2011). These processes may occur sequentially or simultaneously, depending mostly on the gasifier design and biomass feedstock. For an auto thermal gasification (no external heat supply), the thermal energy is supply by combustion step and it drives other processes within the gasification system (Vaezi et al., 2008).

Due to complex nature of reactions occurring in gasification and expensive experimental approach, various mathematical models were developed in an attempt to predict the performance of gasifiers and improve their design (Vaezi et al., 2008). Simulation of gasification process can be done by kinetic modeling, thermodynamic equilibrium modeling, numerical modeling and artificial neural network (Singh et al., 2014). In thermodynamic equilibrium models, assumptions are that the reactions in the pyrolysis and gasification zones are in thermodynamic equilibrium (Jayah et al., 2003). The approach of the model is such that it is independent of the gasifier design and hence it is mostly used to study the influence of biomass type and process parameters (Vaezi et al., 2008). Thermodynamic equilibrium models fit well with downdraft gasifier type as it is the only fixed bed gasifier that contain syngas with lower tar concentration (Pandey et al., 2013).

In this study, analytical and experimental methods have been used to study the performance of downdraft gasifier with rice husk as the biomass feedstock.

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2. MATERIALS AND METHODS

2.1. Materials

The rice husk was collected from Basawa, Zaria, Kaduna State, Nigeria. The proximate and ultimate analyses of the rice husk used in this research are illustrated in Tables 1 and 2 (Salisu et al., 2015).

Table 1: Proximate analysis of rice husk

Proximate Analysis	Parameter (% Dry basis)
Moisture Content	9.88
Volatile Matter	66.12
Fixed Carbon	14.18
Ash	19.70

Table 2: Ultimate analysis of rice husk

Ultimate Analysis	Parameter (% Dry basis)
Carbon	37.55
Hydrogen	4.61
Oxygen	39.47
Nitrogen	0.47
Sulfur	0.00

2.2. Model Development

Thermodynamic equilibrium approach was used in predicting the individual fraction of the syngas. It is based on equilibrium constants and the assumptions used in the model formulation were as follows (Htut et al., 2015):

I. The rice husk is composed of carbon, hydrogen, oxygen and nitrogen elements only, sulfur and other minerals were not taken into account.

II. All the carbon content in the rice husk is converted into gaseous forms and thermodynamic equilibrium is achieved due to enough residence time.

III. The syngas compositions taken into account are CO, CO_2, H_2, CH_4, and N_2. The gases are treated as ideal gas and hydrocarbons other than CH_4 contain in the syngas were assumed negligible. Ash in the rice husk behaves as an inert in all the gasification reactions.

IV. Tar in the syngas is assumed to be negligible; this assumption favors downdraft gasifier since the concentration of tar is relatively low compared with other gasifier configurations.

V. The system is an auto thermal, adiabatic and the pressure drop is assumed to be negligible.

The chemical composition of rice husk can be taken as $CH_xO_yN_z$ (Pandey et al., 2013) and the global gasification reaction can be written as (Vaezi et al., 2008):

$$CH_xO_yN_z + wH_2O + m(O_2 + 3.76N_2) \rightarrow X_1H_2 + X_2CO + X_3CO_2 + X_4H_2O + X_5CH_4 + \left(\frac{z}{2} + m3.76\right)N_2 \quad (1)$$

x, y and z are number of atoms of hydrogen, oxygen, and nitrogen per one atom of carbon in the feedstock; respectively, w and m (equivalence ratio) are the amounts of water and air per one kmol of feedstock, respectively. On the right hand side of Equation (1), X_1 to X_5 are the unknown number of moles of hydrogen, carbon monoxide, carbon dioxide, steam, and methane respectively in the syngas.

$$w = \frac{M_{bm} \times MC}{M_w \times (1 - MC)} \text{ (Zainal et al., 2001)} \quad (2)$$

M_{bm} and M_w are molar mass of biomass and water respectively.

From Equation (1) elemental balance gives:

C: $X_2 + X_3 + X_5 = 1$ (3)

H: $x/2 + w = X_1 + X_4 + 2X_5$ (4)

O: $y + w + 2m = X_2 + 2X_3 + X_4$ (5)

Equations (6) to (10) describe the main reactions occurring in a gasification system namely:

Water-gas	$C + H_2O \leftrightarrow CO + H_2$	+131 kJ	(6)
Boudouard	$C + CO_2 \leftrightarrow 2CO$	+172 kJ/mol	(7)
Methanation	$C + 2H_2 \leftrightarrow CH_4$	-74.8 kJ/mol	(8)
Water –gas shift	$CO + H_2O \leftrightarrow CO_2 + H_2$	-41.2 kJ/mol	(9)
Steam reforming	$CH_4 + H_2O \leftrightarrow CO + 3H_2$	+206 kJ/mol	(10)

Considering Equations (6) to (8) as the major reactions occurring. Combining Equations (6) and (7) gives Equation (9).

The equilibrium constants for the reactions (Equations (8) and (9)) are as follows:

$$K_1 = (X_5/X_1\hat{}2) \quad (11)$$

$$K_2 = (X_3\,X_1)/(X_2\,X_4) \quad (12)$$

$\ln K_1 = 7082.848/T + (-6.567)\ln T + (7.466e^{-3}/2)\,T - (2.164e^{-6}/6)T^2 + 0.701e^{-5}/2T^2 + 32.541$ (Zainal et al., 2001)

$K_2 = \exp(4276/T - 3.961)$ (Barman et al., 2012)

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The enthalpy of reactants entering must be same as enthalpy of products leaving the system.

$$H_{reactants} = H_{products} \quad (13)$$

$$H_{reactants} = H^0_{f,rice\ husk} + w(H_{vap}) + m(H^0_{fO_2} + 3.76H^0_{fN_2})$$

$$H^0_{f,rice\ husk} = LHV + \sum_{i=1}^{n} n_i p_i$$

Where n_i is the number of moles of species i and p_i is the Products of complete combustion of rice husk (kmol) for species i

$$LHV = 4.187\big(81C + 300H - 26(O - S) - 6(9H + m)\big)\ (kJ/kg)$$ (Basu, 2010).

$$H_{products} = \sum_{1\le i\le 5} X_i\big(H^0_{f,i} + C_{p,i}\Delta_{T-298}\big) + \left(\frac{z}{2} + 3.76m\right) C_{p,N_2}\Delta_{T-298}$$

T is the gasification temperature, C_p is determined using an empirical relation:

$$C_p(T) = c_1 + c_2T + c_3T^2 + C_4T^3\ (kJ/kg)$$

Where c_1 to c_4 are coefficients of specific heat capacity

Equation (13) can be simplified into equation (14) as follows:

$$dH_{rice\ husk} + wdH_{H_2O} = X_1dH_{H_2} + X_2dH_{CO} + X_3dH_{CO_2} + X_4dH_{CH_4} + X_5dH_{H_20} + \left(\frac{z}{2} + 3.76m\right) N_2 \quad (14)$$

$$dH_i = H^0_{f,i} + C_{p,i}\Delta_{T-298}$$

$$dH_{H_20(l)} = H_{vap}$$

$$dH_{rice\ husk} = H_{frice\ husk}$$

From equations 3, 4 and 5

$$m = 1/2\,(- X_1 + 3X_2 + 4X_3 + x/2 - 2 - y) \quad (15)$$

From Equations 3 and 11:

$$K_1X_1^2 + X_2 + X_3 - 1 = 0 \quad (16)$$

Substitution of equation 3 and 4 into 12 gives

$$-K_2\,(X_1\,X_2) + (w + x/2 - 2)K_2X_2 + 2K_2{X_2}^2 - X_3\,X_1 + 2K_2X_2\,X_3 = 0 \quad (17)$$

Substitution of Equation 3, 4, 15 into 14 gives:

$$AX_1 + BX_2 + CX_3 + DX_4 + E \quad (18)$$

Where:

$$A = dH_{H_2} - dH_{H_2O(v)} - ((3.64 + z/2)/2)dN_2$$
$$B = dH_{CO} + 2dH_{H_2O(v)} - dH_{CH_4} + ((3.64 + z/2)3/2)dN_2$$
$$C = dH_{CO_2} + 2dH_{H_2O(v)} - dH_{CH_4} + ((3.64 + z/2)4/2)dN_2$$
$$D = dH_{H_2O(v)} - dH_{H_2O(l)}$$
$$E = dH_{CH_4} + 1.26dH_{H_2O} + ((3.64 + z/2)/2)(x/2 - 2 - y)dN_2 - dH_{biomass}$$

The coefficients X_1 to X_3 were obtained by solving Equations 16, 17 and 18 using Newton's Raphson method in MATLAB by supplying elemental compositions of rice husk and moisture content to determine syngas composition. Once the input parameters were defined, the program automatically calculated the equivalence ratio to maintain the pre-set temperature with respect to moisture content.

2.3. Experimental Procedure

The gasifier is a throated downdraft with an internal diameter of 30 cm and a height of 82 cm, grate capacity of height 10 cm and diameter 30 cm. Each experimental run started by loading the gasifier with about 2 kg of rice husk. After charging the biomass, the gasifier was sealed using silicone gasket maker to prevent leakages. The start-up procedure involves ignition of the rice husk through the ignition port, air supply through the port to sustain the ignition with the help of air blower reserved in negative pressure direction resulting in driving air out of the gasifier. This process takes 10 minutes, the ignition port was then closed and the direction of the air blower was changed to the positive pressure direction to supply air to the gasifier through the air supplying port. The flow rate of the air was varied; 0.7, 3.0 and 6.4 L/min. The experiment could not be carried out above air flow rate of 6.4 L/min due to the limitation of the air blower. Gasification reaction occurred with interaction between the gasifying agent (air) and the rice husk inside the gasifier. Figure 1 shows a schematic diagram of the experimental set-up of the gasification system.

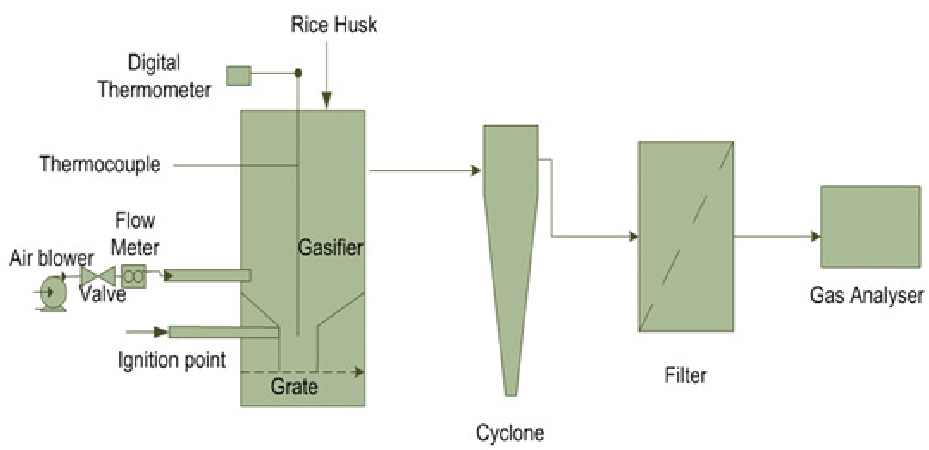

Figure 1: Schematic diagram of the experimental set-up of the gasification system

The syngas produced was then withdrawn from the bottom of the gasifier. Ash component generated from the gasification reaction passed through the lower part via a perforated grate and it is collected by ash collection part at the bottom of the gasifier. The syngas produced moved out of the gasifier to a cyclone and filter for cleaning to remove particulates.

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The cleaned syngas was then sampled with an online portable infrared gas analyzer (Gasboard 3100P series) where CO, CO_2, H_2, CH_4, O_2 as composition and calorific value of the syngas were determined as a function of time. The oxidation zone temperature was also monitored and recorded with time using a K-type (chromel-alumel) thermocouple as temperature sensor and the digital thermometer (UT 350) as temperature indicator and recorder.

3. RESULTS AND DISCUSSION

3.1. Equilibrium Modeling of Rice Husk Gasification

Figures 2 and 3 show simulation results of the rice husk gasification using air as the gasifying agent between reaction temperatures of 500 to 1100 °C. Simulated output parameters are syngas composition and desired syngas components. Desired syngas components represent the combination of combustible gases (H_2, CO and CH_4) in the syngas, and calorific value. It is observed that the diluent nature of N_2 in the syngas increases with temperature from 39 to 60%. Wu et al. (2009) reported that as temperature increases in air gasification, N_2 in the syngas also increases, resulting in lowering the heating value of the syngas. H_2 increased between 500 and 600 °C, from 16 to 19% and decreased from this point to 10% at 1100 °C, with the best value recorded at 600 °C as 19%. CO increased from 14% at 500 °C to a peak value of 19% at 800 °C and then decreased to 18% at 1100 °C. CO_2 decreased gradually from 21% at 500 °C to 12% at 1000 °C, and then remains at about 12% at 1100 °C. This is because boudouard backward and water-gas shift reactions (Equations 7 and 9) that produce CO_2 are all exothermic reactions which are favoured at lower temperatures and at 1100 °C the reaction begins to shift from gasification to combustion due to increase in oxygen. CH_4 also decreased from 11% at 500 °C to about 0% at 1100 °C, because the reactions that produce methane (methanation and steam reforming; Equations 8 and 10) are favoured at lower temperature due to their exothermic nature.

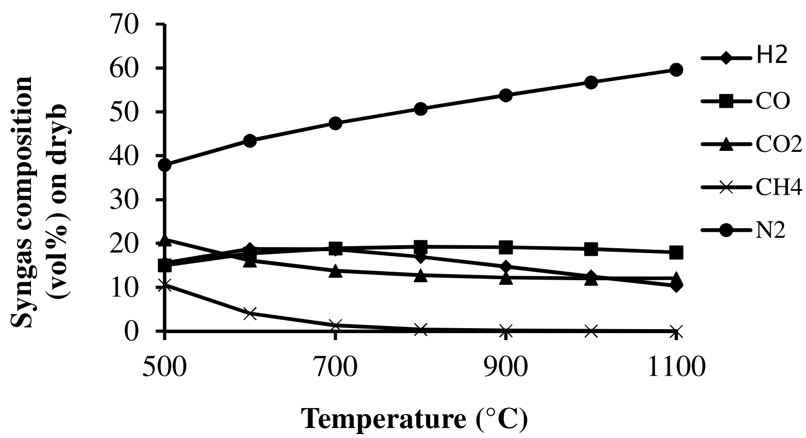

Figure 2: Simulation results of rice husk gasification using air

Equivalence ratio is a parameter that measures how gasification is supplied with less oxidant than would be required for stoichiometric combustion. It is defined as the ratio of the amount of oxygen (air) supplied and the amount of oxygen (air) needed for stoichiometric combustion of biomass feedstock. A value of one (1) indicates combustion and a value of zero (0) indicates pyrolysis, while gasification takes place in between the two values. From Figure 3 it is observed that the equivalence ratio increases as temperature increased from 0.22 at 500 °C to 0.53 at 1100 °C. As the equivalence ratio increases, more oxygen will be available for the exothermic oxidation which then increases the temperature. The calorific value and desired syngas component decreased as the temperature increased between 500 and 1100 °C, from 8 to 3 MJ/Nm^3 and 40% to 27%, respectively. This could be attributed to decrease in CH_4 and increase in N_2 which dilute the syngas as the temperature increased

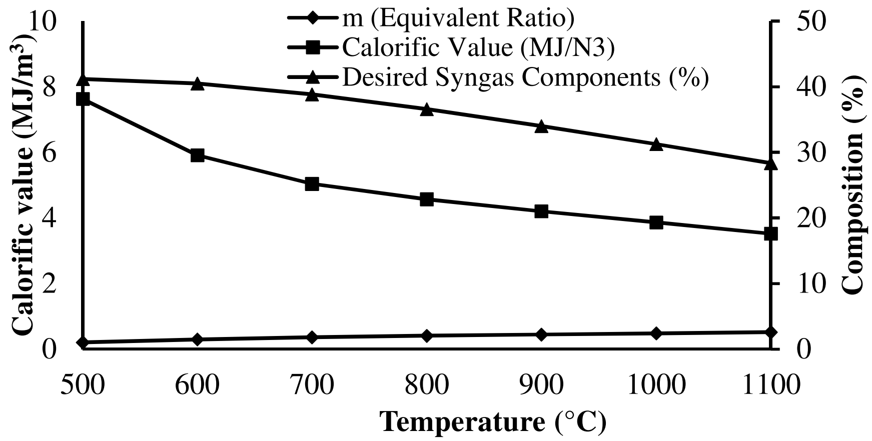

Figure 3: Variation of equivalence ratio and syngas calorific values with gasification temperature

3.2. Experimental Rice husk Gasification Using Different Air Flow Rates

3.2.1. Effects of air flow rate on composition and calorific value of syngas

In gasification, both exothermic and endothermic reactions occur, thereby influencing the composition of the syngas. Figure 4 shows variation of syngas composition and calorific value of syngas with time at 6.4 L/min air flow rate. It is observed that CO increases with time to a peak value of 12% at 30 minutes and then decreased to 7% at 50 minutes, while CO_2 increases with time beginning from 1 to 14% at 50 minutes. These two components (CO and CO_2) are vital in knowing whether the reactions at any point are more of combustion or gasification. The rise and fall of CO is due to the fact that at higher temperatures more biomass was combusted resulting in less material to gasified, thereby producing more CO_2 than CO (Wu et al., 2009; James et al., 2014). The same trend was observed with CH_4 and H_2 as that of CO, CH_4 from 1% to a peak value of 3% at 30 minutes and then decreased to 2% at 50 minutes. H_2 increased from 0% at the beginning to a maximum value of 1% after 20 minutes and then decreased to 0% at 50 minutes. Similar trends of syngas composition with time were recorded with airflow rates of 3 and 0.7 L/min (Figures 5 and 6). The best composition is considered at point where CO is higher than CO_2; 6.4 L/min recorded the overall best composition as 11% CO, 10% CO_2, 2% H_2 and 1% CH_4 after 20 minutes. The least was observed at 0.7 L/min as 5% CO, 5% CO_2, 1% CH_4 and 0% H_2 after 40 minutes. Best composition of 6.39% CO, 6.36% CO_2, 1.3% H_2 and 0.5% CH_4 was achieved at 3 L/min air flow rate after 30 minutes.

Syngas calorific value is a function of the combustible gases (H_2, CO and CH_4) in the syngas and is referred to as desired syngas components (DSC). Individual component of syngas has calorific value in MJ/Nm^3 of 37.1, 13.1, 11.2 for CH_4, CO and H_2 respectively, (Tasma et al, (2009). Highest syngas calorific values were recorded at the highest desired syngas components (DSC) of 15.6, 9.3 and 6.2% as 2.5, 1.5 and 1.0 MJ/Nm^3 for 6.4, 3.0 and 0.7 L/min air flow rates, respectively (As shown in Figures 4, 5 and 6).

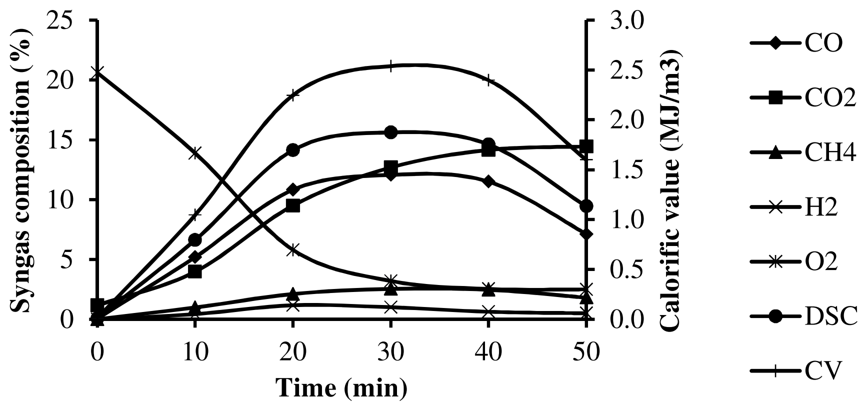

Figure 4: Variation of syngas composition and calorific value of syngas with time at 6.4 L/ min air flow rate

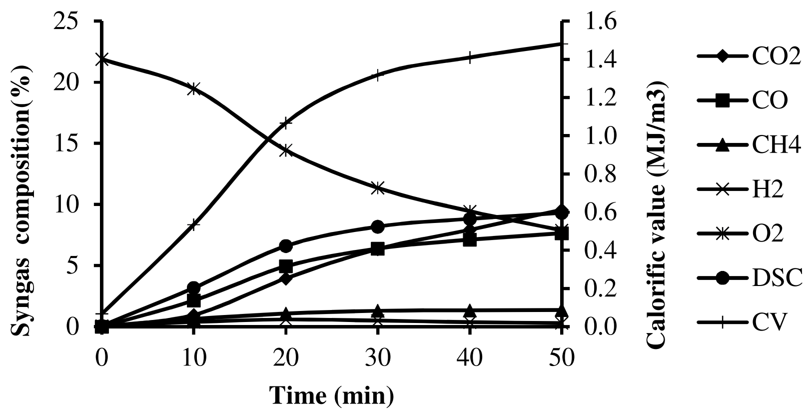

Figure 5: Variation of syngas composition and calorific value of syngas with time at 3.0 L/ min air flow rate

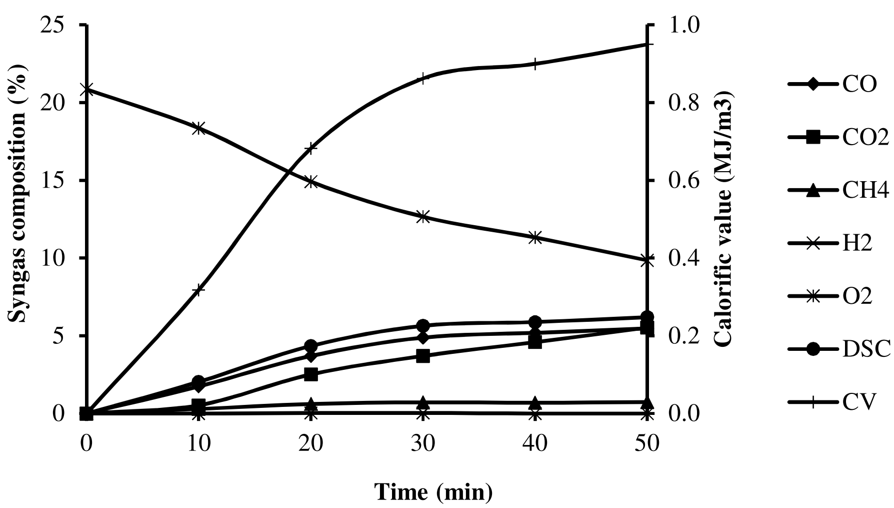

Figure 6: Variation of syngas composition and calorific value of syngas with time at 0.7 L/ min air flow rate

3.2.2. Effects of air flow rate on temperature and equivalence ratio

Table 3 shows relationship between the desired syngas components, calorific value, average oxidation temperature and equivalence ratio. The average temperatures recorded were 567, 250, and 178°C for flow rates of 6.4, 3.0 and 0.7 L/min respectively. It can be deduced that oxidation temperature in gasification increases with air flow rate, which is justified because in an auto-thermal gasification, exothermic reaction at the oxidation zone releases heat required for the system. Equivalence ratio followed the same trend with temperature, that is, increases linearly with increased in temperature. This is because more air input translates to higher equivalence ratio and more combustion, which in turn elevates the temperature of the gasifier.

Table 3: Temperatures and calorific values at different air flow rate

Air Flow rate (L/min)	6.4	3	0.7
Calorific value (MJ/Nm^3)	2.54	1.48	0.95
Temperature (°C)	567	250	178
Desired syngas components (%)	15.62	9.31	6.20
Equivalence ratio	0.128	0.62	0.14

3.3. Comparison between Model and Experimental Results

The model developed was validated using the experimental data obtained in this work and literature experimental data using the universal testing method of root mean square error (RMSE) in Equation 19.

$$RMSE = \sqrt{\frac{\sum_{i}^{N}(\text{Experimental} - \text{model})^2}{N}} \tag{19}$$

The RMSE was obtained as 7.58 with individual values as 7.89, 14.56, 3.54, 0.79 and 1.74 units for CO, H_2, CO_2, CH_4 and calorific value respectively for experimental data of this work. While for the literature experimental data, 2.37 RMSE was calculated with individual values as 3.82, 3.08, 0.15, 2.01 and 0.06 units for CO, H_2, CO_2, CH_4 and calorific value respectively. The reason for higher value of RMSE for the present experiment is due to fact that the literature experiments reported in Table 4 were done at 800 °C except for Yoon, (2012)'s experiment which was conducted between 600-850 °C while for the present experiment, an average temperature of 567 °C was used. The present experiment represents the best syngas composition at the highest air flow rate of 6.4 L/min. In addition, 0.128 equivalence ratio is less than the predicted value suggested by the present model of 0.42, which is due to research limitation of not been able to go beyond 6.4 L/min air flow rate.

Table 4: Comparison between model and experimental values

Syngas gas components	ER	CO	H_2	CO_2	CH_4	Caloric Value (MJ/Nm^3)	RMSE
Literature model	-	16	18.43	-	0.84	4.07	-
Present Model	0.420	18.72	16.68	13.05	0.39	4.47	-
Literature Experiment	0.45-0.60	14.9	13.6	12.9	2.4	5.44	2.37
Present Experiment	0.128	10.83	2.12	9.51	1.18	2.54	7.58

3.4. Performance Analysis of the Experimental Rice Husk Gasification

The carbon conversion efficiency (CCE) which is defined by Equation (20) (Makwana et al., 2014) measures the chemical efficiency of the process (Arena, 2012). A value of 1.0 (100%) indicates total conversion of the carbonaceous feedstock into gaseous products; while a value of 0 (0%) indicates none of the fuel carbon is

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converted (Sweeney, 2012). A comparison between the chemical energy of the syngas and that of biomass fuel is indicated by Cold Gas Efficiency (CGE), which is defined by equation (22) (Makwana et al., 2014)

$$CCE = \frac{Y(CO\% + CH_4\% + CO_2\%) \times 12}{22.4 \times C\%} \times 100 \quad (20)$$

Where Y= dry gas yield (Nm^3/kg) expressed by Equation (20), CO%, $CH_4\%$ and $CO_2\%$ are the composition inside the syngas.

$$Y = \frac{Q_a \text{ x } N_a}{W_b(1 - X_{ash}) \times N_p} \quad (21)$$

Where Q_a is the flow rate of the gasifying agent supplied (Nm^3/h), W_b is the mass flow rate of biomass (kg/h), N_a is the nitrogen in gasifying medium and N_p is the nitrogen in syngas.

$$CGE = \frac{Y \text{ x } LHV_{gas}}{LHV_{biomass}} \quad (22)$$

Where LHV_{gas} and $LHV_{biomass}$ are the heating values of the syngas and biomass in MJ/ m^3 and MJ/Kg respectively.

From Table 5, the highest CCE and CGE were achieved as 21.27 and 12.55% respectively with the highest air flow rate of 6.4 L/min, while the lowest air flow rate recorded the least CCE and CGE of 1.14 and 0.51%, respectively.

Table 5: Performance analysis of gasification

Air (L/min)	CCE (%)	LHV (MJ/Nm^3)	CGE (%)
0.7	1.14	0.95	0.51
3.0	7.03	1.32	3.46
6.4	21.27	2.53	12.55

4. CONCLUSION

A detailed rice husk gasification studies was carried out analytically and experimentally with the following conclusions drawn:

1. A mathematical model was successfully developed using equilibrium approach to predict rice husk gasification using air as gasifying agent between 500 and 1100 °C. The results of the model suggested an optimum temperature of 800 °C and equivalence ratio of 0.42 with syngas composition of 18.72% CO, 16.68% H_2, 13.05% CO_2, 0.39% CH_4, and 4.47 MJ/m^3 calorific value
2. Increase in air flow rate (0.7, 3.0 and 6.4 L/min) during the experimental air gasification favours oxidation temperature, equivalence ratio, syngas composition, and calorific value. The best syngas composition recorded was at 6.4 L/min with composition of 10.83% CO, 9.51% CO_2, 2.12% H_2 and 1.18% CH_4, desired syngas composition of 15.62 % and equivalence ratio of 0.128, with an average temperature of 567 °C and 2.54 MJ/Nm^3 calorific value.
3. Validation of the model developed was done with the best experimental results obtained from rice husk air gasification and gave a root square mean error value of 7.58.
4. Performance analysis of rice husk experimental gasification using air as gasifying agents showed that carbon conversion efficiency (CCE) and cold gas efficiency (CGE) increased with increase in air flow rate. Highest CCE and CGE were achieved as 21.27 and 12.55%, respectively.

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6. CONFLICT OF INTEREST

There is no conflict of interest associated with this work.

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