COMPUTER-AIDED SIMULATION OF A FLUIDIZED-BED REACTOR FOR THE PRODUCTION OF BIOFUELS FROM RICEHUSK BIOMASS

Dagde K.K
Rivers State University
NIGERIA
dagde.kenneth@ust.edu.ng

Akpa J.G
Rivers State University
NIGERIA
akpa.jackson@ust.edu.ng

Viura A.T
Rivers State University
NIGERIA
abbey.viura@yahoo.com

ABSTRACT

This research work focused on the simulation of a Fluidized-Bed Reactor for the production of biofuels from biomass (rice husk) using Advanced System Process Engineering Plus Simulation Software (ASPEN Plus software). The Aspen plus simulation was based on experimental set up and findings for rice husk gasification from literature. Major conversion rates for Reaction Kinetics in a gasifier reactor were obtained from literature. The Simulation model was validated with experimental data from a pilot scale gasification plant obtained from literature as well. During the simulation hydrodynamic parameters were calculated. Results obtained showed reasonable agreement with experimental data with a maximum deviation of 20.6%. The effect of air-fuel ratio and steam-fuel ratio together with temperature on product gas composition was studied. Optimal operation points to achieve self-sufficient conditions for energy was at the temperature of 800^0C, while air-fuel ratio and steam-fuel ratio was at 0.02 and 1.77 respectively. The maximum carbon conversion efficiency achieved was 71.1%.

Keywords: Gasification, Aspen Plus, Fluidized-bed reactors, Biofuels, Syn gas, Rice husk.

INTRODUCTION

Energy demand by humans is on an increasing rise. This is because energy is used for so many things from powering our homes and appliances to even cooking our meals. This dependency on energy has however led to our over reliability on fossil fuels as major source of energy which has caused huge damage to our health and environment. Considering the expensive and negative effect of fossil fuels (chiefly petroleum or crude oil) there is need to find cheaper and less harmful sources of energy that can be used for similar purposes. One of such option is Biomass, which is assumed to be one of the biggest wellsprings of energy, third from oil and coal (Werther et al., 2000).

Biomass alludes to any natural or carbonaceous material which originate from plants or creatures that is alive or as of late dead. These include both plant residues and animal waste. (Loppinet, S. 2008). Biomass is the main source of bio-fuels production (Latiff, A. 1999). We can readily find biomass all around us. Some of these organic less sulphur content materials include rice husk, saw dust, sugarcane bagasse, wood etc.

Among the various types of biomass available, this research will focus on the utilization of rice husk, since rice is readily available to us and the rate of its production is on an increase in Nigeria today.

The main focus of this study is to produce biofuels from Rice husk biomass using a fluidized-bed gasifier while utilizing Aspen Plus software package to simulate biomass gasification. The gasification process in this work is simulated as an air-steam blown fluidized-bed reactor consisting of a bubble phase and an emulsion phase.

Waste rice husk can be converted to wealth through the following key stages: drying, separation, thermal decomposition or pyrolysis of the biomass feed, combustion and char gasification.

Throughout this paper, biomass is assumed to be a plant residue under the category of cellulosic/lignocellulosic, i.e rice husk; and syngas (i.e produced gas) will be used interchangeably in place of biofuels.

Among the various simulation models developed there have been more emphasis on simulating fluidized-bed reactors based on certain configurations of the bed mostly two- region configuration technique with hydrodynamic parameters embedded.

Abdelouahed et al., (2012) simulated a double fluidized bed (DFB) reactor for biomass gasification by using Aspen Plus and dedicated Fortran file on the Tunzini Nessi Equipment Companies (TNEE Technology). Sensitivity analysis was carried out for the process, but only the dynamic (kinetic) model was used. The bed hydrodynamics were dismissed.

Abdullah, H. (2016) simulated biomass gasification using Unisim software. He discovered that optimum operating conditions for the gasifier was achieved using steam as gasifying agent. However his simulation model was incapable of generating product such as methane, due to the use of different software other than Aspen Plus.

Hildegunn et al., (2015) also in his simulation with a dual configuration of fuidized-bed for livestock manure and wood chip gasification didn't predict the carbon conversion efficiency of the feed and the gasification efficiency.

This research work presents an aspect of fluidized-bed reactor simulation with a dual configuration of two-plug flow reactors in parallel for the production of biofuels from Rice husk, using ASPEN Plus simulator software. The present simulation model incorporates both kinetic model (i.e. considering reaction kinetic and reactor hydrodynamics) and thermodynamic equilibrium model (i.e. neglecting reaction kinetic and reactor hydrodynamics) as gasifier simulation models to simulate the gasification process. Also important parameters such as carbon conversion and cold gas efficiency were determined in the process. Most importantly the incorporation of data from different works for the design was important in order to develop a self-sufficient model for gasification.

MATERIALS AND METHODS

Materials

Aspen Plus Software was utilized which is most effective for solid components such as Rice husk. (AspenTech, 2014). A fluidized-bed reactor configured as two plug flow reactors in parallel was used since the process utilizes a solid catalyst.

The materials for this work include a flow sheet description of biomass gasification for the generation of biofuels (syngas) as depicted in Figure 1. Operating and kinetic parameters for the simulation were obtained from literature as presented in Table 1 and 2. Table 3, 4a and 4b show the physical properties of biomass and bed material; total carbon, nitrogen, oxygen , hydrogen and sulfur percentages measured by Ultimate analysis and the volatile matter, fixed carbon, moisture and ash content in the biomass sample measured by proximate analysis respectively (Rajesh, T. 2013) .

Table 1: Operating parameters (Sharmina et al., 2014)

Parameter	*Unit*	*Value*
Feed	Flow rate (kg/h)	4.5
	Pressure (MPa)	0.3
	Temperature (°C)	25
Air	Flow rate (kg/h)	4.5
	Pressure (MPa)	0.3
	Temperature (°C)	350
	Air/fuel ratio	1
Steam	Flow rate (kg/h)	27
	Pressure (MPa)	0.3
	Temperature (°C)	200
	Steam/fuel ratio	6
Reaction vessel volume	Total (m^3)	2.5
	Waste/char capacity (m^3)	1.75
	Freeboard capacity (m^3)	0.75
Gasifier	Pressure (MPa)	0.3
	Temperature (°C)	700-1100
Dryer	Pressure (MPa)	0.3
	Temperature (°C)	400
Decomposition	Pressure (MPa)	0.3
	Temperature (°C)	400

Table 2: Reaction Kinetics (Xie et al., 2013; and Umeki et al., 2010)

Reactions	Reaction rate
Water-gas reaction: $C(s) + H_2O \longrightarrow CO + H_2$	$r = 1.272 * m_s * T * \exp\left(\frac{-22645}{T}\right)(H_2O) \quad (1a)$
$CO + H_2 \longrightarrow C(s) + H_2$	$r = 1.044 * 10^{-4} * m_s * T^2 * \exp\left(\frac{-6319}{T} - 17.29\right)(H_2)(CO) \quad (1b)$
Boudouard reaction: $C(s) + CO2 \longrightarrow 2CO$	$r = 1.272 * m_s * T * \exp\left(\frac{-22645}{T}\right)(CO_2) \quad (2a)$
$2CO \rightarrow C(s) + CO_2$	$r = 1.044 * 10^{-4} * T^2 * \exp\left(\frac{-2363}{T} - 20.92\right)(CO)^2 \quad (2b)$
Methanation reaction: $0.5C(s) + H_2 \longrightarrow 0.5CH_4$	$r = 1.368 * 10\text{-}3 * ms * T * \exp\left(\frac{-8078}{T} - 7.087\right)(H_2) \quad (3a)$
$0.5CH_4 \longrightarrow 0.5C(s) + H_2$	$r = 0.151 * ms * T0.5 * \exp\left(\frac{-13578}{T} - 0.372\right)(CH_4)^{0.5} \quad (3b)$

Water gas shift reaction:

$CO + H_2O \rightarrow CO_2 + H_2$ r = 7.68 * 10[10] * T * exp $$\left(\frac{-36640}{T}\right)(CO)^{0.5}(H_2O) \qquad (4a)$$

$CO_2 + H_2 \rightarrow CO + H_2O$ r = 6.4 *10[9] * T * exp $$\left(\frac{-39260}{T}\right)(H_2)^{0.5}(CO_2) \qquad (4b)$$

Methane-reforming:

$CH_4 + H_2O \rightarrow CO + 3H_2$ r = 3.1005 * exp $$\left(\frac{-15{,}000}{T}\right)(CH_4)(H_2O) \qquad (5a)$$

$CO + 3H_2 \rightarrow CH_4 + H_2O$ r = 3.556 *10[-3] * T * exp $$\left(\frac{-15000}{T}\right)(CO)(H_2)^2 \qquad (5b)$$

Table 3: Physical Properties of Biomass and bed material (Rajesh, T. 2013)

Property	Main particle size (mm)	Apparent Density (kg/m³)	Porosity	Sphericity
Bed material				
Sand	0.38	2650	0.44	0.77
Biomass				
Rice husk	0.53	426	0.81	0.37

Table 4a: Ultimate Analysis (Rajesh, T. 2013)

Types of Biomass	Carbon (%)	Hydrogen (%)	Nitrogen (%)	Sulphur (%)	Oxygen (%)
Rice husk	38.45	4.96	0.82	0.18	55.59

Table 4b: Proximate Analyses (Rajesh, T. 2013)

Biomass sample	Moisture content (%)	Volatile matter (%)	Ash content (%)	Fixed carbon (%)
Rice husk	7.34	56.37	15.83	20.46

Methods

Apsen Plus Simulation Model Development

This study was done with the use of ASPEN Plus a broad process modeling computer software package utilized because of its colossal limit and exact results in modeling processes.

The simulation incorporated the accompanying steps: (a) stream class specification (b) choice of property method, (c) specifying the particular component from the databank and distinguishing non-convectional and conventional components (d) connecting unit operation blocks with material streams (defining the process flow sheet) (e) feed stream specification (including specifying composition, thermodynamic condition and flow rate) (f) specification of unit process blocks and chemical reactions where necessary.

Assumptions

Presumptions made in displaying the gasification procedure are as per the following (Nikoo, M. & Mahinpey, N. 2008)

- The process of simulation is kept under a steady state condition
- The process is isothermal in nature
- Biomass de-volatilization is instantaneous

- The entire gas is consistently appropriated inside the emulsion stage.
- Particle size is not considered.
- The particle diameter stays constant all through the process of gasification.
- Char comprises of just carbon ash
- Pressure drops are neglected.

The stream class used in Aspen Plus was MIXCISLD and the property method used is Redlich-Kwong-Soave (RKS) cubic equation of state with Boston-Mathias alpha function (RKS-BM). The RKS-BM property method is recommended for gas processing, refinery, and petrochemical applications such as gas plants, crude towers and ethylene plants. Using RKS-BM, reasonable results can be expected at all temperatures and pressure. The RKS-BM property method is used for non-polar or mildly polar mixtures. Examples are hydrocarbons and light gases, such as carbon dioxide, hydrogen sulphide, and hydrogen. (AspenTech, 2010). HCOALGEN and DCOALIGT for pre-specified coal model are the enthalpy and density models selected respectively for both feed and ash which are non-conventional components in ASPEN plus; since ASPEN package doesn't have a conventional solid designed for biomass feed and ash.

Next for each nonconventional solid, ULTANAL, PROXANAL and SULFANAL analysis were entered to indicate the basic structure of the solids. For Ultimate examination, Ultanal was used to categorize the composition of the biomass feed and ash based on weight percentage of carbon and ash content available in the feed. The analysis by Sulfanal on the other hand separates between different types of sulfur that is available in the nonconventional item. Table 4a and 4b summarizes the compositions of the biomass feed.

Process Description

The Biomass feed is introduced as a non-convectional solid into a R-Stoic reactor (DRY-REAC) where it is dried. At that point water is isolated through SEP1 and after that the strong blend is nourished into a disintegration reactor-R-YIELD working at 400^{o}C which changes over the biomass into traditional segments by figuring its definitive investigation and proximate examination. An adding machine is utilized to decide the yield of the parts.

Then water is separated through SEP1 and then the solid mixture is fed into a decomposition reactor-R-YIELD operating at 400^{o}C which changes over the biomass into conventional components by calculating its proximate analysis and ultimate analysis. A calculator is used to determine the components yield.

The disintegrated mixture then enters into an R-Gibbs reactor operating at 400^{o}C where it is further heated (combusted). Both the char and volatiles (COMBST) are sent into a mixer together plus steam and air therefore ready for the gasification reaction. The MIX-PROD is then split into two, where each fraction goes into the PFR reactors in parallel configured as the bubble and emulsion phase, for the remainder of the endothermic reactions. The outlet stream from the gasifier is sent to the mixer-MIX-OUT and then to a separator block SEP 2 where solid is separated from gas.

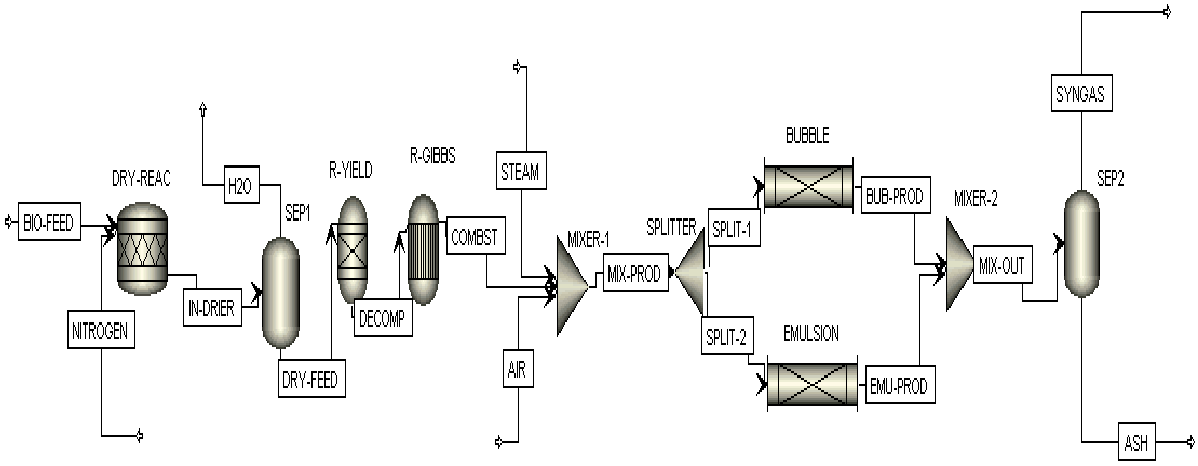

Figure 1: Flow sheet description of the gasification process

Material and Energy Balance Equations

Material Balance (Input Parameters)

The input parameters for the material balance was obtained from ultimate analysis as depicted in Table 4a and data obtained from simulation result.

HHV_f = 16.2MJ/Kg, where, HHV_f = Higher heating value of feed (total energy input) or gross calorific value of the fuel.

The basis for the simulation was given as follows:

The supply rate for dry air was 2.76kg/kg of biomass feed, while the supply rate for steam was 0.117kg/kg of biomass feed. The air moisture content i.e. moisture per kg of dry air or specific humidity of air was 0.01kg of H_2O. While ambient temperature was 25°C.

Nitrogen percent in air was given as 75.47%, and Oxygen percent in air was given as 23.2%. Molecular weight of Nitrogen was 28, Molecular weight of Oxygen was 16, Molecular weight of Hydrogen was 2, Molecular weight of Carbon was 12, Molecular weight of Steam (H_2O) was 18.

The Standard Volume occupied by gas was given as 22.4 nm^3

Solving for the amount of gas produced per kg of each feed component.

Nitrogen Balance

(Inflow) $\pm$ (Depletion/production due to reaction) = (Outflow) + ~~(Accumulation)~~ (6)

Nitrogen was fed into the gasifier from several points. These include Nitrogen from air, and Nitrogen proportion from feedstock all reacting together to give the product i.e. Dry gas yield.

Equation (7) and equation (8) depicts the amount of Nitrogen entering and leaving the gasifier.

$$N_2 \text{ flow in (kmol/kg feed)} = \frac{(N_2\,\%\,\text{air x Dry air supply} + N_2\,\%\,\text{in feed})}{(\text{Mw of } N_2)} \quad (7)$$

$$\text{Dry gas yield (kmol/kg feed)} = \frac{(N_2 \text{ flow in kmol/kg feed})}{(N_2\,\%\,\text{in product gas})} \quad (8)$$

Oxygen Balance

Oxygen was fed into the gasifier from several points. These includes Oxygen from air, Oxygen associated with steam entering the gasifier, Oxygen from moisture in fuel, Oxygen from moisture in air and oxygen proportion from product all reacting together to give the total oxygen flow to the gasifier.

The total Oxygen leaving the gasifier includes Oxygen associated with Carbon monoxide and Carbon dioxide in dry product gas, all reacting together with the molecular weight of oxygen to steam (H_2O) ratio in the gasifer.

Equation (9) depicts the total oxygen flow into the gasifier. Equations (10), (11), (12) and (13) where used to obtain equation (9).

Equation (14) depicts the total amount of oxygen leaving the gasifier. Equations (15) and (16) where used to obtain equation (14).

Total O_2 flow to gasifier = O_2 air flow to gasifier + O_2 with Steam $(H_2O)_f$ + O_2 from moisture in fuel + O_2 from moisture in air + O_2% in product fuel (9)

O_2 air flow to gasifier = O_2% air x Dry air supply (10)

$$O_2 \text{ with Steam } (H_2O)_f = \frac{\text{Mw of } O_2}{\text{Mw of Steam } (H_2O)} \text{ x Steam } (H_2O) \text{ supply} \tag{11}$$

$$O_2 \text{ from moisture in fuel} = O_2 \text{ from moisture in fuel x } \frac{\text{Mw of } O_2}{\text{Mw of Steam } (H_2O)} \tag{12}$$

$$O_2 \text{ from moisture in air} = O_2 \text{ from moisture in the air feed x Dry air supply x } \frac{\text{Mw of } O_2}{\text{Mw of Steam } (H_2O)} \tag{13}$$

Total O_2 in product gas = O_2 with CO, CO_2 in dry (product) gas + O_2 with Steam $(H_2O)_p$ 14)

O_2 with CO, CO_2 in dry (product) gas = (half x CO% in product gas + one x CO_2% in product gas) x (Dry gas yield kmol/kg feed) (15)

$$O_2 \text{ with Steam } (H_2O)_p = O_2 \text{ with CO, } CO_2 \text{ in dry (product) gas x } \frac{\text{Mw of } O_2}{\text{Mw of Steam } (H_2O)} \tag{16}$$

Hydrogen Balance

Hydrogen was fed into the gasifier from several points. These includes Hydrogen from the biomass feedstock, Hydrogen associated with steam entering the gasifier, Hydrogen from moisture in fuel, Hydrogen from moisture in air all reacting together to give the total Hydrogen flow to the gasifier.

The total Hydrogen leaving the gasifier includes Hydrogen associated with Hydrogen in product gas and Methane, all reacting together with their respective moles.

Equation (17) depicts the total hydrogen flow into the gasifier. Equations (18), (19), (20) and (21) where used to obtain equation (17).

Equation (21) depicts the total amount of hydrogen leaving the gasifier.

Total H_2 flow to gasifier = H_2 % in fuel + H_2 with Steam $(H_2O)_f$ + H_2 from moisture in fuel + H_2 from moisture in air (17)

$$H_2 \text{ with Steam } (H_2O)_f = \frac{\text{Mw of } H_2}{\text{Mw of Steam } (H_2O)} \text{ x Steam } (H_2O) \text{ supply} \tag{18}$$

$$H_2 \text{ from moisture in fuel} = H_2 \text{ from moisture in fuel x } \frac{\text{Mw of } H_2}{\text{Mw of Steam } (H_2O)} \tag{19}$$

H_2 from moisture in the air = H_2 from moisture in the air feed x Dry air supply x

$$\frac{\text{Mw of } H_2}{\text{Mw of Steam } (H_2O)} \qquad (20)$$

Total H_2 in product gas = H_2 assoc. with H_2, CH_4 in dry (product) gas

H_2 assoc. with H_2, CH_4 in dry (product) gas = (H_2% in product gas + two x CH_4% in product gas) x (Dry gas yield kmol/kg feed) x two (21)

Carbon Balance

All the Carbon leaving the gasifier includes Carbon associated with Carbon monoxide, Carbon
dioxide and Methane in the product gas, all reacting together in their respective proportions. Equation (22) depicts the total amount of Carbon leaving the gasifier.

C assoc. with CO_2, CO and CH_4 in dry gas = (CO_2% in product gas + CO% in product gas + CH_4% in product gas) x (Dry gas yield kmol/kg feed) x Mw of C (22)

Carbon conversion

By separating the total carbon in the product (i.e. carbon escaping the gasifier) by the Carbon proportion (%) in the fuel based on ultimate analysis, we obtain the carbon conversion efficiency
(i.e. the amount of carbon that has been converted during the process)

Equation (23) depicts the total amount of carbon that was converted in the process.

$$\eta_c = \frac{\gamma(CO\% + CO_2\% + CH_4\%)\,product}{C_{feed}\,\%} \text{ x Mw of C x 100 \%} \qquad (23)$$

where,

$\gamma =$ Dry gas yield i.e. Quantity of product gas per kg of feed (or production rate)

η_c = Carbon conversion efficiency

Energy Balance for the Gasifier with respect to Computer Aided Simulation.

The performance of biomass gasification characterized as the proportion of chemical energy in the gas to that in the fuel which is represented as the cold-gas efficiency is calculated thus:
Equation (24) depicts the chemical energy proportion of the fuel.
Equation (25) depicts the Higher heating value of product gas (i.e. total energy output)

$$\eta_{cg} = \frac{(HHV_g \times \gamma \times \text{std. vol. occupied by gas})}{(HHV_f)} \text{ x 100\%} \qquad (24)$$

HHV_g of product gas = CO (HHV) x CO% in product gas + H_2 (HHV) x H% in product gas + CH_4
(HHV) x CH_4% in product gas) x Dry gas yield kmol/kg feed x std vol. occupied by gas. (25)

where,

HHV_f = Higher heating value of feed (i.e. total energy input) or gross calorific value of the fuel

RESULTS AND DISCUSSION

Validation of Simulation result with Experimental Data

Table 5 shows the comparison between predicted result and experimental value obtained from Sharmina et al., (2014). The range of compositions between predicted simulation and experimental values were in good agreement.

The deviations observed may be due to differences in inlet feed composition for different biomass materials (i.e. between solid waste and rice husk). Also reactor specification based on yield distribution especially in the R-yield reactor may also influence changes in products composition.

It is important to know that the present simulation result when compared with works by Rajesh, T. (2103), showed some similarities in its product composition. For example, Nitrogen composition in product gas was 50% based on simulation result by Rajesh, (2013), while Nitrogen in the present simulation gave a composition of 49.1%. Other composition results by Rajesh, T. (2013) was given thus: Carbon monoxide with Syngas composition of 9.2%, and methane with a composition of 2.60%.

Table 5: Comparison of Simulation predictions with experimental data obtained from Sharmina et al., (2014)

Measurement (%)	H_2	CO	CO_2	CH_4	N_2	H_2O	Others
Experimental data obtained from (Sharmina et al., 2014)	19	28.5	11.4	1.9	28.5	5.7	5.0
The present simulation model	20.6	10.9	3.1	1.0	49.1	2.1	13.2
Deviation from experimental data	1.6	-17.6	-8.3	-0.9	20.6	-3.6	8.2

Keeping the following parameters constant (i.e. Basis: steam supply rate 0.117kg/kg feed, Biomass feed supply rate of 1kg and Air supply rate 2.76 kg/kg feed), the following values for the present simulation model was obtained.

Material and Energy Balance Calculation results

Table 6: Percentage composition of the gas produced.

Components	% Composition of Gas Produced
CO	10.9%
CO_2	3.1%
N_2	49.1%
H_2	20.6%
CH_4	1.0%

Results for the Material balance, Energy balance and Carbon conversion efficiency

Table 7: Material Balance

Component	Value	
	Material Balance	
Nitrogen Balance		
N_2 flow in (kmol/kg feed)	**0.0746 kmol N_2/kg feed (INFLOW)**	**(7)**
Dry gas yield (kmol/kg feed)	**0.15193kmolgas/kg feed (OUTFLOW)**	**(8)**
Oxygen Balance		
Total O_2 flow to gasifier	**1.3896 kg O_2/kg feed (INFLOW)**	**(9)**
O_2 air flow to gasifier	0.640 **kg/kg feed**	**(10)**
O_2 with Steam $(H_2O)_f$	**0.104 kg/kg**	**(11)**
O_2 from moisture in fuel	**0.065244 kg/kg feed**	**(12)**
O_2 from moisture in air	**0.024533 kg/kg**	**(13)**
Total O_2 in product gas	**0.785 kg/kg feed (OUTFLOW)**	**(14)**
O_2 with CO, CO_2 in dry (product) gas	**0.4156 kg/kg of feed**	**(15)**
O_2 with Steam $(H_2O)_p$	**0.3694 kg/kg of feed**	**(16)**
Hydrogen Balance		
Total H_2 flow to gasifier	**0.07382 kg/kg feed. (INFLOW)**	**(17)**
H_2 with Steam $(H_2O)_f$	**0.013 kg/kg**	**(18)**
H_2 from moisture in fuel	**0.008155**	**(19)**
H_2 from moisture in air	**0.003066**	**(20)**
Total H_2 in product gas i.e H_2 with H_2, CH_4 in dry (product) gas	**0.06867 kgH_2/kg feed. (OUTFLOW)**	**(21)**
Carbon Balance		
C assoc. with CO_2 CO, and CH_4 in dry (product) gas	**0.27347 kg/kg feed (OUTFLOW)**	**(22)**

Table 8: Energy Balance

	Energy Balance (Cold Gas Efficiency)	
η_{cg}	**2.4%**	**(23)**
HHV_g	**931 MJ/nm^3**	**(24)**

Table 9: Carbon Conversion Efficiency

	Carbon Conversion	
η_{cg}	**71.1%**	**(25)**

Sensitivity Analysis with Aspen Plus Model

Prior to the validation of the present ASPEN Plus simulation model with the experimental data obtained from the work of Sharmina et al., (2014), Sensitivity analyses were carried out with the following three process parameters: gasification temperature, air-fuel-ratio, and steam-to-biomass to find optimum operating points. These parameters were varied from 650^{o}C –1050^{o}C, 0.02 to 1.8, and 0.33 to 10.11 respectively.

The Effect of Air-Fuel Ratio

In this study, air-fuel ratio was varied from 0.02 to 1.8 while maintaining a constant temperature of 700^{o}C and keeping Steam to Biomass fuel ratio constant at 0.5. The Feed flow rate was maintained at 4.5kg/hr. In Figure 2 below, the mole fraction of H_2 and CO decreases with increasing amount of air due to oxidation reactions. CH_4 concentration varied very little in this range (i.e. the conc. of CH_4 decreased with small deviations) with increasing air-fuel ratio; while the composition of CO_2 decreased with very small deviation as well. The concentration of N_2 in syngas showed a high level of increase with increasing amount of air supply. This was as a result of increase in Nitrogen content in air.

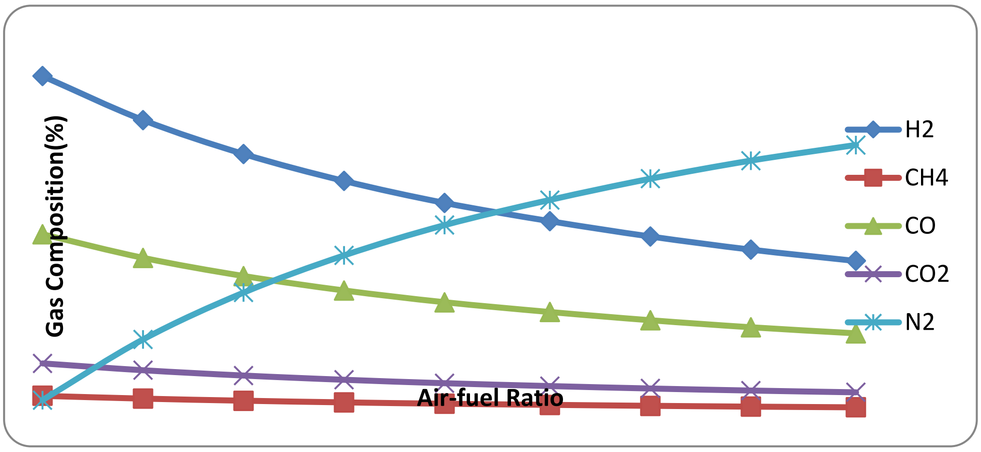

Figure 2: Effect of air-fuel ratio on Syngas composition.

The Effect of Steam-Fuel Ratio

Figure 3 shows the effect of steam-fuel ratio on syngas composition.

The effect of steam flow rate on the composition of product gas was studied by varying the steam-biomass fuel ratio in the range of 0.33 to 10.11 while keeping other parameters constant (i.e. temperature at 700°C; air-fuel ratio at 0.33 and Biomass feed flow rate at 4.5kg/hr).

In Figure 3, the mole fractions of H_2 and CO increased very slowly with an increase in steam-fuel ratio. This is as a result of steam reforming reactions (of CO and H_2) that was taking place as steam flow rate was increased.

The concentration of CO_2 was very small with increasing steam-fuel ratio. CO_2 concentration dropped slowly with little deviations as steam fuel ratio changed from 0.33 to 10.11.

The concentration of CH_4 remained almost the same with N_2 gas following the same trend with very small changes.

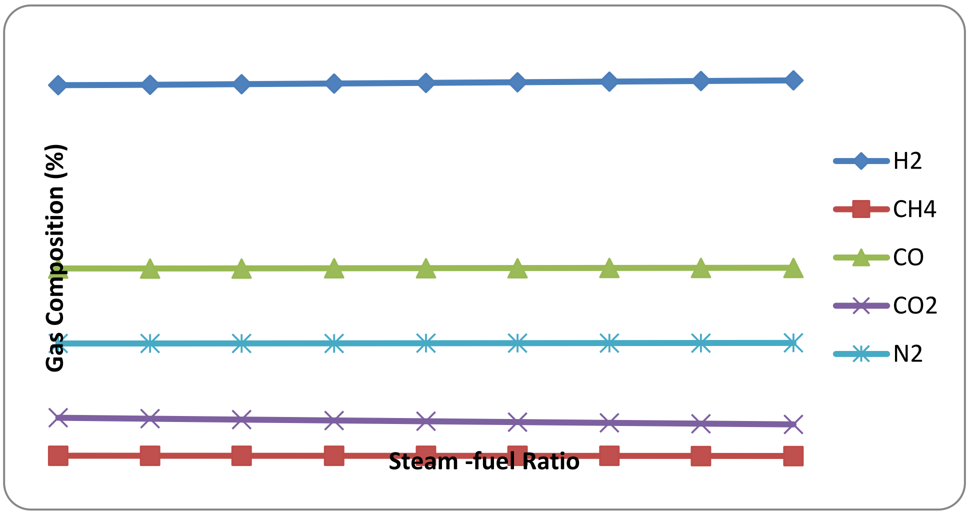

Figure 3: Effect of Steam-fuel ratio on Syngas composition

The Effect of Gasifier Temperature

Figure 4 shows the effect of gasifier temperature on the composition of syngas. Here the composition of syngas varied within a small range with increasing gasifier temperature.

The temperature which was varied from 650°C to 1050°C (with 50°C increment) while keeping other parameters constant (i.e. air-fuel ratio = 0.33 and steam-fuel ration = 0.55, Biomass flow rate = 4.5kg/hr), showed a constant trend in the composition of product gases where H_2, CO, CH_4, N_2 and CO_2 gave compositions of 45%, 24%, 2%, 14% and 7% respectively.
In Figure 4, H_2 gas concentration increased slightly with increase in gasifier temperature. The mole fractions of CH_4 and N_2 did not vary with increase in temperature.
The concentration of CO_2 however increased gradually with very small margin as gasifier temperature was increased.

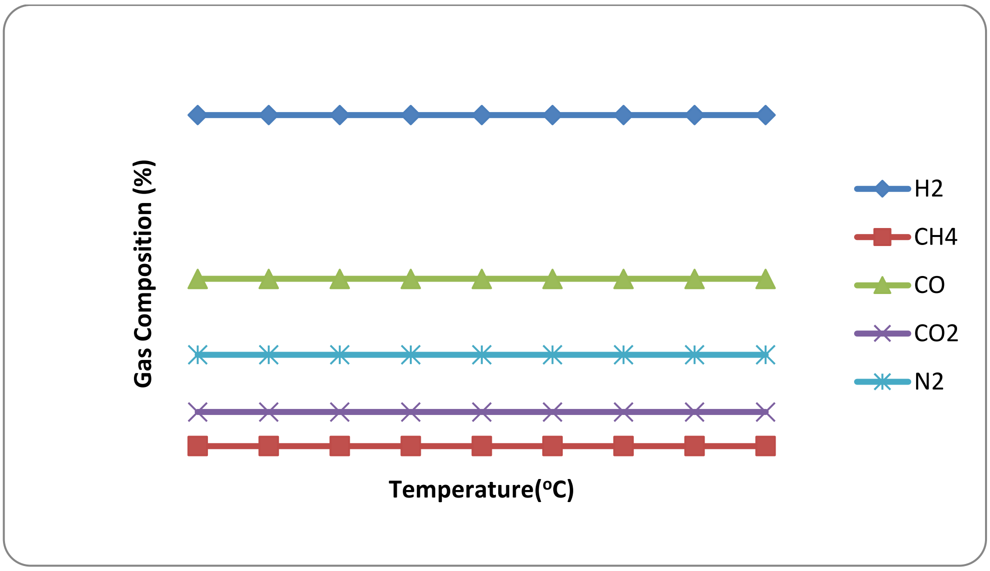

Figure 4: Effect of Gasifier temperature on Syngas composition

CONCLUSION

This research work simulated a fluidized bed reactor to produce biofuels (syngas) from rice husk using Aspen plus simulation software tool. The Aspen plus computer-aided simulation was developed based on experimental set up and findings for rice husk gasification by Rajesh, T. (2103). Several Aspen plus reactor blocks were used together with separators, a mixer and splitter block. The simulation study was run to find the relationship among gasification temperature, air-to-fuel ratio, and steam-to-fuel ratio to obtain the energy self-sufficient condition. Optimum condition was found at a gasification temperature of 800°C, air-to-fuel of 0.02, and steam-to-biomass ratio of 1.77. The maximum carbon conversion efficiency achieved was at 71.1%. Simulation model was also validated with experimental data measured by Sharmina et al., (2014). A very good agreement was found between simulation and experimental results with a maximum variation of 20.6%. The deviation may be due to the differences in feed materials compared based on their compositions. Biomass is a promising technology due to environmental friendliness; and is an attractive alternative energy system. The model can be used to predict gasifier performance; and can serve as basis for further studies.

REFERENCES

Abdelouahed et al. (2012). Detailed Modelling of Biomass Gasification in Dual Fluidized Bed Reactors under Aspen Plus.

Abdullah, H. (2016). Simulation of biomass gasification, instituto politecnico de braganca, 1-53.

AspenTech, (2010). Aspen Physical Property System, Physical Property Methods. *Version Number: V7.2*.

AspenTech, (2014). Jump Start: Solids Process Modeling in Aspen Plus. Retrieved from https://processdesign.mccormick.northwestern.edu/index.php/Reactor

Hildegunn et al. (2015). Simulation of gasification of livestock manure with Aspen plus. Linkoping 271-276.

Jenkins, B. (1989). Physical properties of biomass. In: Kitani, O., Hall, C.W. (Eds.), Biomass Handbook. Gordon & Breach Science Publishers, Amsterdam.

Ke Sun, (2014). Optimization of biomass gasification reactor using Aspen plus. Telek University College.

Kishore, A. (2008). Renewable Energy Engineering & Technology: A Knowledge Compendium. New Delhi: TERI Press.

Latiff, A. (1999). A Study of the Design of Fluidized Bed Reactors for Biomass Gasification; University of London: London, UK. 1- 215.

Loppinet et al. (2008). Current and foreseeable applications of supercritical water for energy and the environment. ChemSusChem. 1(6):486-503.

NAN, (2017). Rice production in Nigeria increases to 5.8m tones in 2017-RIFAN: Available at: https://punchng.com/rice-production-in-nigeria-increases-to-5-8m-tonnes-in-2017-rifan/

Nikoo, M., & Mahinpey N. (2008). Simulation of biomass gasification in fluidized bed reactor using ASPEN Plus. *Biomass and Bioenergy* 32, 1245-1254.

Rajesh, T. (2013). Production of hydrogen gas from biomass waste using fluidized bed gasifier, 1-69.

Sharmina et al., (2014). An Experimental and Numerical Investigation of Fluidized Bed Gasification of Solid Waste. Energies *7*, pg 43-61; doi:10.3390/en701004.

Umeki et al., (2010). High temperature steam-only gasification of woody biomass. *Applied Energy*, 87,791-798.

Werther et al., (2000). ‘Combustion of agricultural residues’. Progress in Energy and Combustion Science 26, 27.

Xie et al., (2013). Lagrangian method for three-dimensional simulation of fluidized bed coal gasification. *Advanced PowderTechnology*, 24, 382- 392.