

A thermodynamic Equilibrium model of Fluidized bed Gasifier using ASPEN HYSYS

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Abstract— A steady state thermodynamic equilibrium model for biomass gasification in atmospheric fluidized bed gasifier was developed using Aspen Hysys version 10. The model addressed the physical properties of the oil palm frond (OPF) and the chemical reaction involved in the process. This chemical reactions is embedded in sequential set of reactors: conversion and equilibrium reactors. Oil palm frond (OPF) decomposition into constituents in the pyrolysis zone is modeled with a pyrolytic yield reactor. The combustion of char and volatiles in the combustion zone were modeled with a conversion and equilibrium reactor respectively. The gasification zone was also modeled with conversion and equilibrium reactor. The models of the gasification process were validated with both experimental data and simulation results from literature. The optimal condition of the process operating parameter like gasification temperature, steam-biomass ration and air-fuel ratio where found to influence the syngas compositions. Increase in temperature increases the hydrogen and carbon- monoxide composition in the syngas. The optimum temperature in the various zones of the gasifier: drying, pyrolysis, and volatile combustion where 300, 500 and 850 respectively and gasification temperature at the three gasifiers(A, B and C) are 940, 207 and 653 respectively. The steam to biomass ratio of 1.11 and air to fuel ratio of 0.104 were the optimal gasification condition. Steam to biomass increase favours the production of H₂ and CO₂, which also increases the heating value of the synthesis gas.

Keywords— Aspen Hysys, Biomass, conversion, gasification, optimum parameters.

I. INTRODUCTION

Global warming and climatic change have been a recurrent problem facing the earth. The major causes of climate change and global warming is the increasing concentration of carbon dioxide (CO₂), and other greenhouse gases in the atmosphere introduced primarily through human activities (IPCC, 2007). Recent research and development effort have focused on the use of renewable resources like agricultural products (biomass) that provides many ecological services such as timber and fuel wood, habitat for fauna and flora protection of soil quality, fruits and food materials, medicinal products, recreation facility, material for genetic improvement and sustenance of environmental quality (Nzegbule, 2008) to mitigate against climatic change.

Biomass is a significant source of useful energy with fewer environmental impact created by our everyday activities across the world than fossil fuel (Maniatis *et al*, 1993). Forests and agricultural farms plays a vital role in the global carbon cycle because they store huge amount of carbon in the biomass and soil. Biomass absorbs CO₂ from the atmosphere

and through photosynthesis converts it to carbohydrate stored in form of woody tissues and other vegetable matter, the CO₂, is then returned to the environment after combustion. Biomass is CO₂, neutral making it an advantageous fuel source and a dominant choice for replacement of fossil fuels as the concern of global warming increases (Nikoo and Mahinpey, 2008).

Biomass can be converted into commercial products via either biological or thermochemical processes (Lin and Tanaka, 2006, Caputo *et al*, 2005, Yoshioka *et al*, 2005). Biological conversion of low value lignocellulosic biomass still faces challenges related to low economy and efficiency (Caputo *et al*, 2005). Combustion, pyrolysis and gasification are the three main thermochemical conversion methods. Biomass is traditionally combusted to supply heat and power in the process industry. The net efficiency for electricity generation from biomass combustion is usually very low, ranging from 20% to 40% (Yoshioka *et al*, 2005). Pyrolysis converts biomass into bio-oil in the absence of oxygen (O₂).

The limited used and difficulty in downstream processing of bio-oil have restricted the wide application of biomass pyrolysis technology (Faaij, 2006). Gasification converts biomass through partial oxidation into a gaseous mixture, small quantities of char and condensable compounds. It is considered one of the most efficient ways of converting the energy embedded in biomass and it is becoming one of the best alternatives for the reuse of waste solids. Gasification occurs in a well designed equipment called the gasifier.

A lot of research work have been done on design of gasification reactor. There exist several designs of the reactor and this has resulted in the availability of various reactors. The reactors are classified based on the gasification agent, heat source, gasifier pressure, fixed bed or fluidized bed. (Rauch, 2003):

The fixed-bed gasifier has a bed of solid fuel particles through which the gasifying media and gas either move up (updraft), move down (downdraft) or are introduced from one side of the reactor and are released from the other side on the same horizontal level (cross-draft). It is the simplest type of gasifier, usually consisting of a cylindrical space for fuel and gasifying media with a fuel-feeding unit, an ash-removal unit and a gas exit. In the fixed-bed gasifier, the fuel bed moves slowly down the reactor as the gasification occurs. Fixed-bed gasifiers are simple to construct and generally operate with high carbon conversion, long solid residence time, low gas velocity and low ash carry-over (Carlos, 2005, Reed).

Fluidized bed are classified as bubbling, circulating and twin-bed. The gasifying agent is blown through a bed of solid particles at a sufficient velocity to keep the particles in a state of suspension. Fuel particles are introduced at the bottom of the reactor, are very quickly mixed with the bed material, and almost instantaneously are heated up to the bed temperature. As a result of this treatment, the fuel is pyrolyzed very fast, resulting in a component mix with a relatively large amount of gaseous materials. Further gasification and tar-conversion reactions occur in the gas phase. Twin-bed gasification uses two fluidized-bed reactors. The biomass enters the first reactor, where it is gasified with steam, and the remaining char is transported to the second reactor, where it is burnt with air to produce heat. The heat is transported to the gasification reactor by the bed material, normally sand. The flue gas and the product gas have two separate exits. (Puig-Arnavat, 2010). Entrained-flow gasifiers are commonly used for coal because they can be slurry-fed in direct gasification mode, which makes solid fuel feeding at high pressures inexpensive. These gasifiers are characterized by short

residence time, high temperatures, high pressures and large capacities (Knoef, 2005).

Fluidized bed gasifiers are advantageous for transforming biomass, particularly agricultural residues, in to energy. It also have perfect contact between gas and solid, along with a high degree of turbulence, improves heat and mass transfer characteristics, enhances the ability to control temperature and increases heat storage and volumetric capacity (Sadaka *et al*, 2002).

Nigeria is among the largest oil palm producing countries of the world after Malaysia and Indonesia. Oil palm tree (OPT) produces an average of 6 oil palm frond (OPF) in month. during pruning per oil palm tree. This waste is allowed to decay or burnt in farmlands which causes grave yard risks and environmental problems (Khiyami *et al*, 2008). OPF can be gasified to synthesis gas which can further be processed into liquid fuels, adding oil exports of the country while managing the waste dumping and burning issues. During gasification, biomass is reacted with limited amount of oxygen in the presence of a gasifying agent (steam, air or pure oxygen). The oxygen in it oxidizes a portion of biomass, generating heat which helps to maintain the gasifier temperature and drives endothermic gasification reaction (Bassyouni *et al*, 2014). The heating value of syngas depends on the gasification medium used: steam gasification results in syngas with a heating value of 10 – 18MJ/Nm³ (Basu, 2010). This paper is on the development of a steady state simulation of an atmospheric fluidized bed gasification for the production of syngas using Aspen Hysys software. Aspen Hysys have been used by few investigators to study simulation of biomass gasification; example include biomass/coal gasification systems integrated with fuel cell (Ersoz *et al*, 2006), simulation of IGCC technologies (Nieto *et al*, 2008) and simulation of gasification and purification gas units. Aspen Hysys has inbuilt data bank of conventional constituent which made it easier to model solid component by using its ultimate and proximate analysis.

II. DESCRIPTION OF THE GASIFICATION PROCESS

A process design for synthesis gas production from biomass gasification in a bubbling fluidized bed gasifier is shown in Figure 1. It is a bubbling fluidized bed attached with a cyclone.

It is designed for biomass gasification fed with air and steam into inside the reaction chamber. The advantage of bubbling fluidized gasifier is excellent gas – solid mixing and large thermal inertia which ensure excellent heat and mass transfer,

low tar formation and lower risk of particles agglomeration (Basu, 2010; Basu, 2006). These advantages make it suitable for application in medium sized unit (<25M_{wth}) using

pulverized feedstock (particle size <10mm) in a hot bed of inert materials (Basu, 2010).

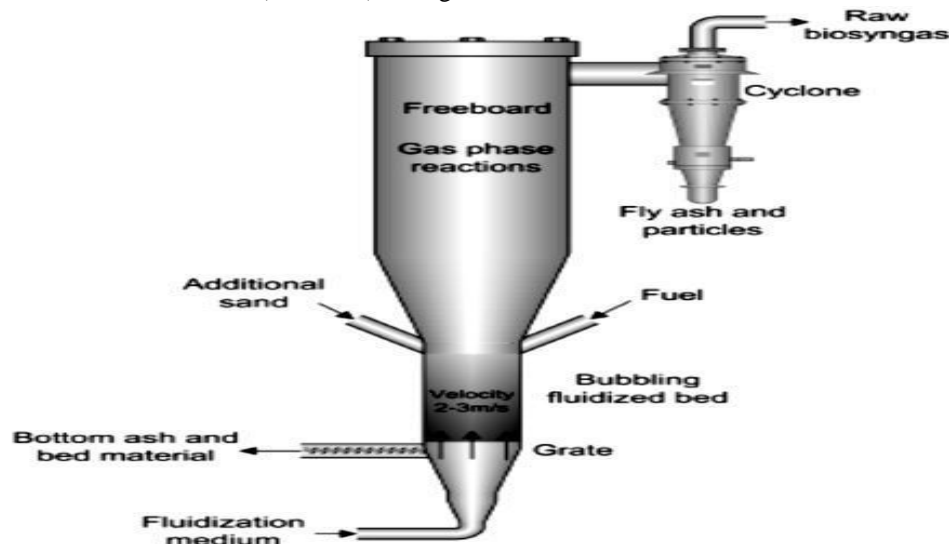


Fig.1: Bubbling Fluidized Bed (Puig-Arnavat, 2011)

During operation, the bed materials are heated to the desired temperature of gasification but maintained below 900°C for biomass feedstock to avoid agglomeration. The feedstock and hot bed materials are subsequently fluidized using air, steam or oxygen (Nyakuma *et al*, 2012). As soon as biomass is fed into the bottom of the bubbling fluidized bed, an exquisite contact occurs between the hot bed material and biomass which rapidly exchange heat and mass. The overall process of biomass gasification in the bubbling fluidized bed can be divided into four steps (Laihongshen *et al*, 2008): the first step is drying, where the moisture of biomass evaporates. The second step is where volatile compounds in biomass evaporate is called devolatilization. This is followed by pyrolysis, the step where the major part of the carbon content of biomass is converted into gaseous compounds. The result of the pyrolysis is, apart from gases, a carbon-rich solid residue called char. In the last step, the char is partly gasified with steam and converted into gaseous products. The amount of un-reacted char is a function of gasification process conditions, such as temperature and biomass particles residence time in the gasifier.

The gas stream from the bubbling fluidized bed consists of a mixture of hydrogen, carbon monoxide, carbon dioxide and a small amount of methane and tar. The gaseous independently

exhausts from the gasifier through the cyclone, whereas the un-reacted char with bed particles still remains in the vessel chamber Laihongshen *et al*, (2008)

As the fluidizing gas bubbles rise higher in the gasifier, rapid mixing occurs and other gasification reactions including char oxidation takes place (Basu, 2010; Demirbas, 2008). Table 1 show the gasification reactions. The most popular bed particle is sand, which performs very well mechanically, as evidenced by its wide industrial use in bubbling and circulating fluidized bed combustion applications (Laihongshen *et al*, 2008).

Biomass gasification in the gasifier is an intensive endothermic process. The bubbling and circulation of bed particles serves as a heat carrier, transferring heat from the dense fluidized bed to the freeboard zone inside the gasifier. While the bubbling of the bed particles dominates the endothermic heat in the gasifier, the portion of char in biomass mass between the dense zone and the freeboard zone specifies the exothermic in the gasifier vessel and the efficiency of biomass gasification. Sand plays active role in biomass gasification by providing the necessary heat transfer action since it has high specific heat capacity than the biomass materials.

Table 1: Gasification reactions (McKendry, 2002, Ajaree et al., 2017)

Reaction	Heat of reaction	Reaction name	
$CH_xO_4(\text{biomass}) + O_2(21\% \text{ of air})$ $+ H_3O(\text{steam}) \rightarrow CH_4 + CO$ $+ CO_2 + H_2 + H_2O(\text{unreacted steam})$ $+ C(\text{char}) + \text{tar}$		Overall reaction	(1)
Heterogeneous reactions			
$C + \frac{1}{2}O_2 \leftrightarrow CO$	$(-111 \text{ MJKmol}^{-1})$	Partial oxidation	(2)
$C + O_2 \leftrightarrow CO_2$	$(-406 \text{ MJKmol}^{-1})$	Complete oxidation	(3)
$C + CO_2 \leftrightarrow 2CO$	$(+172 \text{ MJKmol}^{-1})$	Boudard	(4)
$C + H_2O \leftrightarrow CO + H_2$	$(+131 \text{ MJKmol}^{-1})$	Water gas	(5)
$C + 2H_2 \leftrightarrow CH_4$	$(-75 \text{ MJKmol}^{-1})$	Methanation	(6)
Homogenous reactions [10, K ₃]			
$CO + \frac{1}{2}O_2 \rightarrow CO_2$	$(-283 \text{ MJKmol}^{-1})$	CO Partial combustion	(7)
$H_2 + \frac{1}{2}O_2 \rightarrow H_2O$	$(-242 \text{ MJKmol}^{-1})$	H ₂ partial combustion	(8)
$CO + H_2O \leftrightarrow CO_2 + H_2$	$(-41 \text{ MJKmol}^{-1})$	Water gas shift reaction	(9)
$CH_4 + H_2O \leftrightarrow CO + 3H_2$	$(+206 \text{ MJKmol}^{-1})$	Steam-methane reforming	(10)
Hydrogen sulphide (H ₂ S) and ammonia (NH ₃) formation reactions			
$H_2 + S \rightarrow H_2S$	Not reported	H ₂ S formation	(11)
$\frac{1}{2}N_2 + \frac{1}{2}H_2 \leftrightarrow NH_3$		NH ₃ formation	(12)

III. PROCESS SIMULATION

In order to simulate the chemical steps occurring in the process of biomass gasification in bubbling fluidized beds, the software package of Aspen is adopted. It is a steady state chemical process simulator, which was developed at Massachusetts Institute of Technology (MIT) for the US DOE, to evaluate synthetic fuel technology (Doherty et al, 2009). Aspen is universal software for simulation, design and optimization of a complicated chemical process. It is applied to establishing the model of biomass gasification on the basis of principal of mass, chemical and energy balance (Lainhongshen *et al*, 2008). It uses unit operation blocks which are models of specific process operations (reactors, heaters, coolers etc) (Doherty et al, 2009). The user places these blocks on a flow sheet, specifying material and energy streams. An extensive built in physical properties database is used for the simulation calculation. The program uses a sequential modular (SM) approach, that solves the process scheme module by module, calculating the outlet stream properties using the inlet stream properties for each block

(Doherty et al, 2009). Aspen Hysys uses Simulation Basis Manager (SBM) as welcome interface for simulation project and helps mainly in selecting and defining pure component, assigning a property package for carrying out flash and physical properties calculations, and defining reaction which can be embedded into any unit operation during the simulation process (Bassyouni *et al*, 2014). Oil palm frond which is not a library component in Aspen Hysys was modeled as a solid hypothetical component, using ultimate analysis as shown in Table 2, the process flow diagram of the OPF gasification in bubbling fluidized bed is shown in Figure 2. Peng Robinson equation of state (EOS) was selected as property package to well estimate the physical properties of components in an OPF waste simulation. The gasification reactions are defined as equilibrium reactions in SBM, specifying equilibrium constants as a function of temperature. Because of the influence of hydrodynamic parameters on biomass gasification in a fluidized beds, both hydrodynamic and reaction must be treated simultaneously (Nikoo and Mahinpey, 2008).

Table.2: Parameters input in simulation study

Biomass Feedstock (OPF)		
Proximate analysis		
- Moisture content (MC)	wt. %	12.39
- Volatile matter (VM)	wt. % dry basis	67.65
- Fixed carbon (FC)	wt. % dry basis	17.00
- Ash	wt. % dry basis	2.96
- Average density	Kg/m ³	350
- Particle size	Mm	0.67
- Higher calorific value	MJ/KJ	17.26
Ultimate analysis		
- Carbon	wt. % dry basis	48.50
- Hydrogen	wt. % dry basis	5.80
- Oxygen	wt. % dry basis	44.75
- Nitrogen	wt. % dry basis	0.79
- Sulphur	wt. % dry basis	0.002
- Chlorine	wt. % dry basis	0.158
Flow rate	Kg/h	100
Air Feedstock		
Temperature	°C	65
Flow rate	Nm ³ /h	0.8
Steam Feedstock		
Temperature	°C	250
Flow rate	Kg/h	20
Operating Condition		
Temperature	°C	850-940
Pressure	Atm	1

The gasification of OPF in a bubbling gasifier is simulated in four main stages. The first stage simulates preheating of biomass using a splitter unit. Where the biomass OPF is fed as a wet material and then dried, separating it from water before introducing it to the next stage of biomass decomposition. The pyrolysis reactor yield was modeled to simulate the decomposition of the biomass. Thus biomass is

defined as a hypothetical component in Hysys which is decomposed to its constituting conventional components of carbon, hydrogen, nitrogen, oxygen and sulfur, using ultimate analysis. The result of the simulation of pyrolytic reactor are the product of char from proximate analysis and volatile gases H₂, CO, CH₄, CO₂, H₂O, other hydrocarbon and tars.

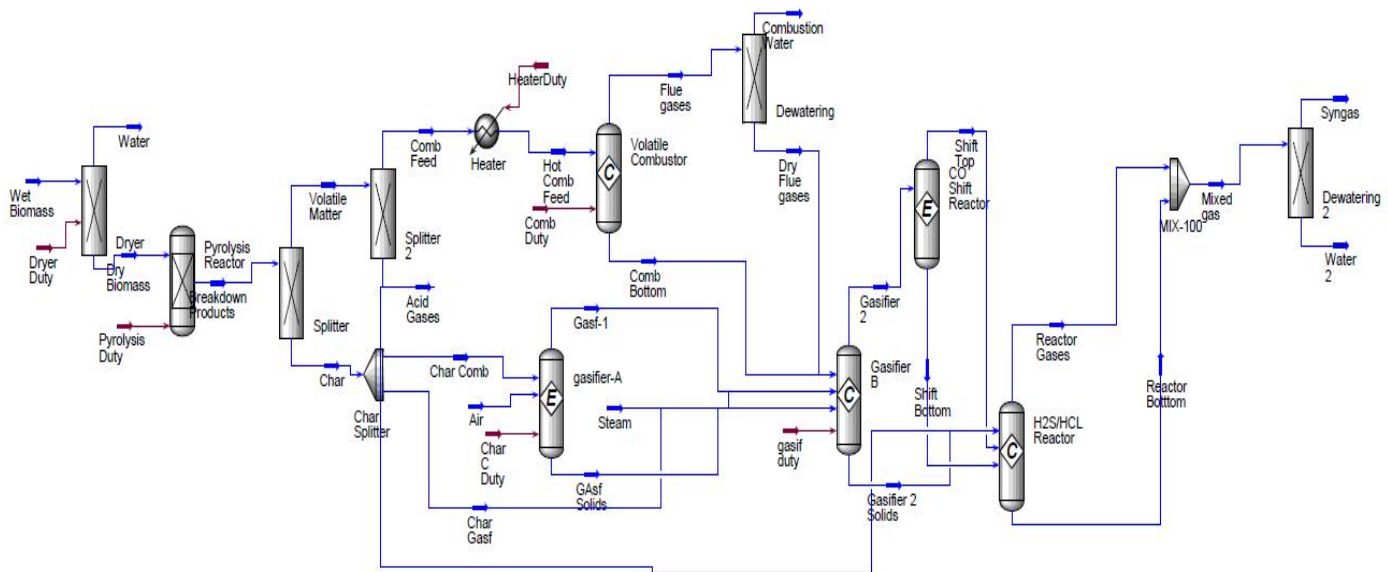


Fig.2: Process Flow Diagram for OPF Aspen Hysys Simulation

The third zone simulates the combustion of the volatile matter or gases which follows Gibbs equilibrium, it is modelled with an equilibrium reactor in Hysys named volatile combustor. The gasification model simulates the gasification reactions, reactions such as the Boudard, the water-gas and the methanation. The products of both the partial oxidation and the gasification zone are feed into additional integrated zone comprising of sets of equilibrium and conversion reactors. This zone sets the final syngas composition, which is composed mainly of H₂, CO, CO₂ and some CH₄.

3.1 Simulation Description

Operating steps of the gasification process of OPF in fluidized bed gasifier are separately considered in Aspen Hysys simulation where series of various unit operation are properly selected, integrated and sequenced as shown in Figure 2. Assumptions which are similar to the one in the literature are (Shukla and Kumar, 2017; Nikoo and Mahinpey, 2008; Bassyouni *et al*, 2014; Ahmad *et al*, 2016):

1. Steady state isothermal process.
2. Operation at atmospheric pressure (~1 bar).
3. Pressure drops are neglected.
4. Char is 100% carbon (C).

5. N₂ is a diluent and an inert and thus does not react.
6. Fuel bound sulphur (S) and chlorine is converted to H₂S and HCl respectively.
7. Drying and pyrolysis are instantaneous.
8. Tar formation is not considered.
9. A heat stream is used to simulate the heat transferred by the circulation of bed material in the gasifier.
10. Heat loss from the gasifier is neglected.
11. The biomass feed into the gasifier are of uniform size distribution.

The process is simulated in four(4) main stages namely:

- 3.1.1 Drying: The wet biomass feed into fluidized bed gasifier first enters the drying zone of the gasifier where water in the form of moisture present in the biomass as determined by the proximate analysis is driven off as steam, leaving a dry biomass which enters the next unit. The yield of water is specified by the water content in the proximate analysis of the OPF. In the present Aspen Hysys model the drying process is represented by the unit “Dryer”. The process occurs at 150°C.
- 3.1.2 Pyrolysis: This stage represents the biomass decomposition. A yield reactor model in Aspen

Hysys named “Pyrolysis” was used to simulate the decomposition of biomass which closely represents a pyrolysis process in a fluidized bed gasifier in terms of its functionality. Biomass defined as a hypothetical component in Hysys is split into its constituting conventional components of carbon, hydrogen, nitrogen, oxygen, chlorine and sulfur, using ultimate analysis. Based on the assumption, char from “Pyrolysis” consist of pure carbon. The streams “Comb Feed” and “char” in the simulation represent volatile matter and fixed carbon respectively, defined in accordance with the proximate analysis of the parent fuel. The pyrolysis reaction is modelled with a yield reactor. The pyrolysis reaction takes place at 500°C.

3.1.3 Volatile Combustion: It is assumed that the combustion of volatile matter (VM) follows a conversion reaction, it is modeled in Hysys in a reactor named “VM Combustor”. Volatile feed to the VM Combustor, called Hot Comb Feed containing a small amount of carbon, representing gaseous carbon in the volatile matter. Carbon in Hot Comb Feed can be calculated by the difference method using proximate analysis data i.e. calculating what amount of the total amount of the carbon in the fuel is volatile and fixed carbon. The modeling of volatile matter combustion is carried out in accordance with the hydrodynamics of the fluidized bed gasifier, based on the real reactor model. Oxygen supply is limited in the VM combustor. Volatile matter combustion is very exothermic, it supplies heat to endothermic reactions in gasification zone where CO₂ and H₂O coming from the combustion zone reacts with char to form synthesis gas. Thus, combustion products (H₂O and small amount of CO) of volatile matter have their share in the gasification reactions; therefore, flue gas stream from VM Combustor in the simulation is sent to the gasification reactor Gasifier-B. While the bottom product “comb bottom” proceeds into the next zone of the fluidized bed gasifier. The volatile matter combustion reaction takes place at ~850°C

3.1.4 Char Gasification: The gasification reactions are sets of equilibrium reactions. To facilitate modeling in Aspen Hysys the set of the reactions are broken down and modeled in various reactors as follows:

3.1.4.1 Gasifier A: Gasifier A is an equilibrium reactor that models the char combustion in air. Air is feed into the gasifier which indicates that the char combustion occurs in an oxygen rich medium represented by Equation (3), hence the char combustion is very exothermic, it supplies heat to endothermic reactions in gasification char combustion reaction takes at ~940°C

3.1.4.2 Gasifier B: The exiting streams from gasifier A, char, flue gases, mixed with steam enters gasifier B; a conversion reactor modelling gasification zone of fluidized bed gasifier. It models boudouard, watergas, and methanation reactions Equation 4, 5, 6 respectively using conversion method of key reactant. The watergas and boudouard reactions are endothermic while the methanation reaction is exothermic.

3.1.4.3 Gasifier C (Shift Reactor): This is an equilibrium reactor which models water gas shift reaction and methane steam reforming reactions equation 9 and 10 respectively.

3.1.5 H₂S/HCl reactor: This unit models the hydrogen sulfide/hydrogen chloride production reaction where hydrogen reacts with sulfur/chlorine to form hydrogen sulfide and hydrogen chloride respectively.

IV. RESULTS AND DISCUSSION

4.1 Sensitivity Analysis

4.1.1 Effect of Gasification Temperature on Syngas Composition.

The effect of gasifier temperature on produced syngas compositions is shown in Figure 3. The temperature considered varies from 450°C - 1050°C. The gasifier temperature is varied by varying gasifier heat duty. It can be seen in Figure 3 that the composition of hydrogen and carbon monoxide increases from (0.26-0.29 and 0.47-0.49) respectively with increasing temperature, while methane and carbon dioxide decreases from (0.19-0.18 and 0.09-0.07) respectively. A similar trend has been observed for fluidized bed gasifier with various kind of biomass of Nikko and Mahinpey, 2008 and Ajaree *et al*, 2017. Hydrogen is among reactants in the methanation reaction, higher temperature shifts equilibrium backward for this exothermic reaction Equation 6, saving hydrogen from consumption.

The CO shift reaction is also exothermic in behavior and high temperature favors carbon monoxide instead of hydrogen

Equation 9. Thus, overall effect is a net increase in hydrogen composition at higher temperatures.

The gasification reactions; water gas, bouduard, methane-steam reforming produce carbon monoxide and their

endothermic nature is favoured by higher temperature. Therefore, amount of carbon monoxide increases with increase in temperature in the gasifier alongside with high carbon conversion.

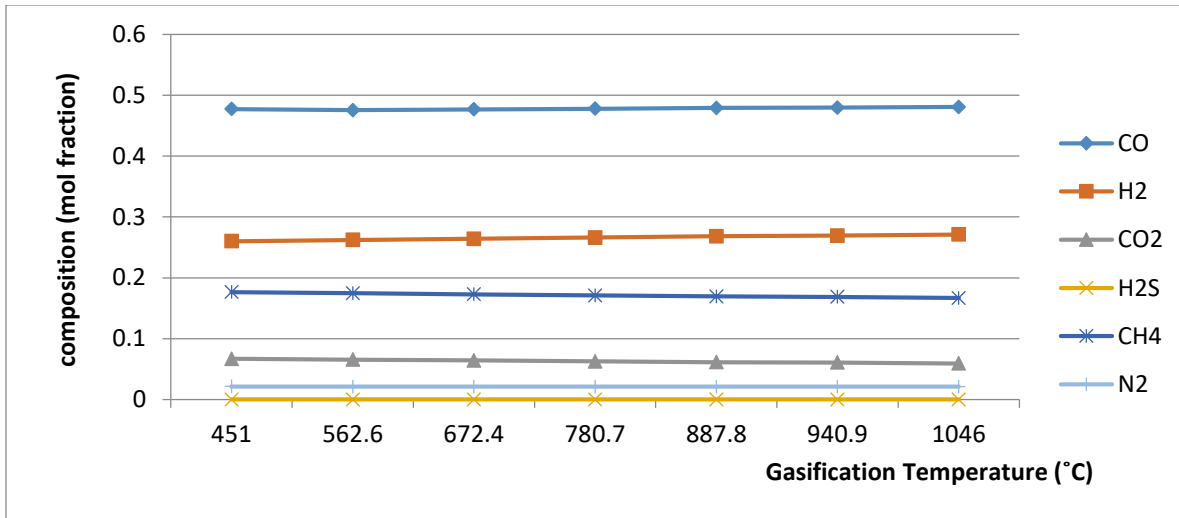


Fig.3: Effect of Gasification Temperature on Syngas Composition

4.1.2 Effect of Steam to Biomass Ratio on Syngas Composition

The effect of increase in steam to biomass ratio (S/B) was studied in fluidized bed gasifier using Aspen Hysys and the simulation results were plotted in Figure 4. Saturated steam at 101.4 kPa and 250°C was used and S/B ratio was varied from 0 to 5. Injecting steam shifts the equilibrium to the right in water gas reaction producing carbon monoxide and hydrogen. From Figure 4 it was observed that increase in steam to biomass ratio increases the net production of

Hydrogen and carbon-dioxide as illustrated in Equation 9 and Equation 10. However, for CO, initial increase in the steam to biomass increase the net production of CO, the production of CO attains a maximum value at a steam to biomass ratio of 1.0 after which further increase in steam to biomass ratio results in the reduction of CO production. This is due to the fact that high steam flow-rate drives the shift reaction in CO shift reactor and thus results in the production of a higher net amount of H₂ thus, the forward reaction is favored.

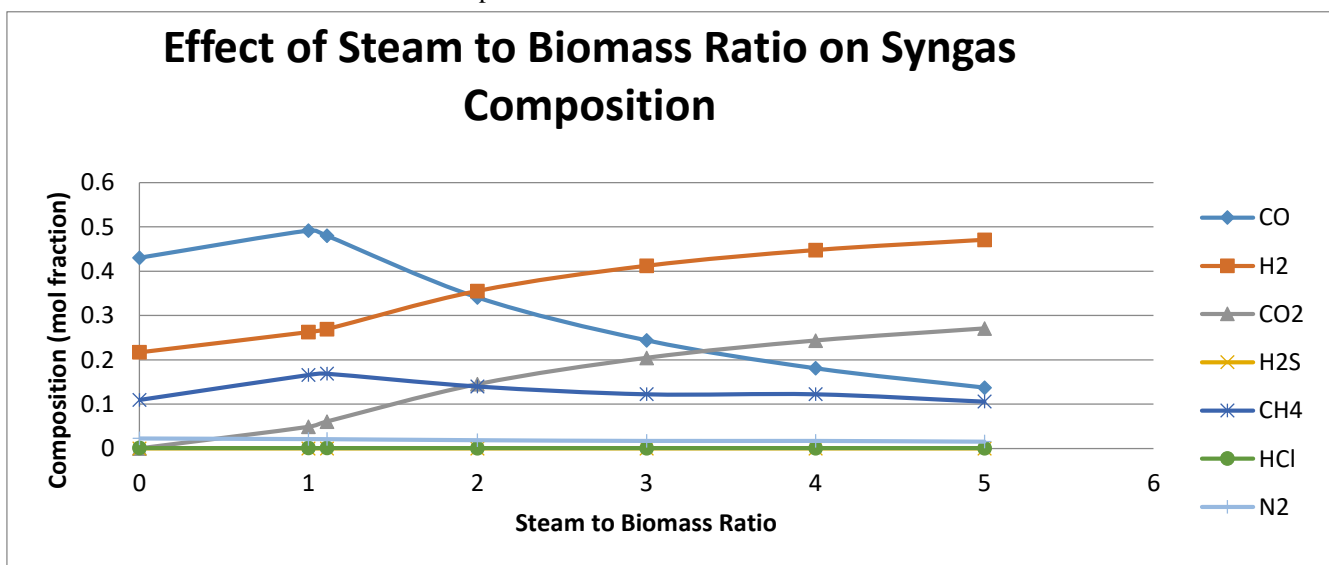


Fig.4: Effect of Steam to Biomass Ratio on Syngas Composition

4.1.3 Effect of Air Flow rate on the Char Combustion zone (Gasifier A) Temperature

The effect of the air flowrate on the combustion zone temperature was studied using ASPEN HYSYS simulator, it was observed that maximum combustion temperature was attained at an air flowrate of 3.5kgmole/hr corresponding to a temperature of 900°C.

As the amount of air is increased above 3.5kgmole/hr, the temperature in the combustor falls because energy is used to heat the extra combustion air. It was also observed that if the air becomes too much, the temperature becomes too low, below “good combustion temperature”, the amount of CO₂ produced in the gasifier begins to decrease due to incomplete combustion because of low temperature.

4.1.4 Effect of Air Fuel Ratio on Synthesis Gas Composition

The effect of air flow on syngas composition was examined. Simulation results for syngas composition were examined when air molar flow ranged between 0-5. In Figure 5 it was

observed that production of both hydrogen and carbon monoxide decreases with increasing amount of air from (0.49-0.22), while hydrogen composition increased linearly upto 0.32 and at air fuel ratio of 3 it starts to decrease upto 0.12, and also the volume of inert gas Nitrogen in syngas increases.

The decrease in hydrogen and carbon-monoxide contents were expected and it is due to a nitrogen dilution effect. Higher air flow can also cause syngas quality to degrade because the air flow rate decreases the combustion zone temperature and subsequently the temperature in the gasification zones. Because the endothermic reactions depend on the heat received from the combustion zone to drive the reaction to higher conversion, thus the increased air fuel ratio implies increase air flow and lower combustor temperature which yields lower reaction conversion for the gasification reaction and low synthesis gas composition.

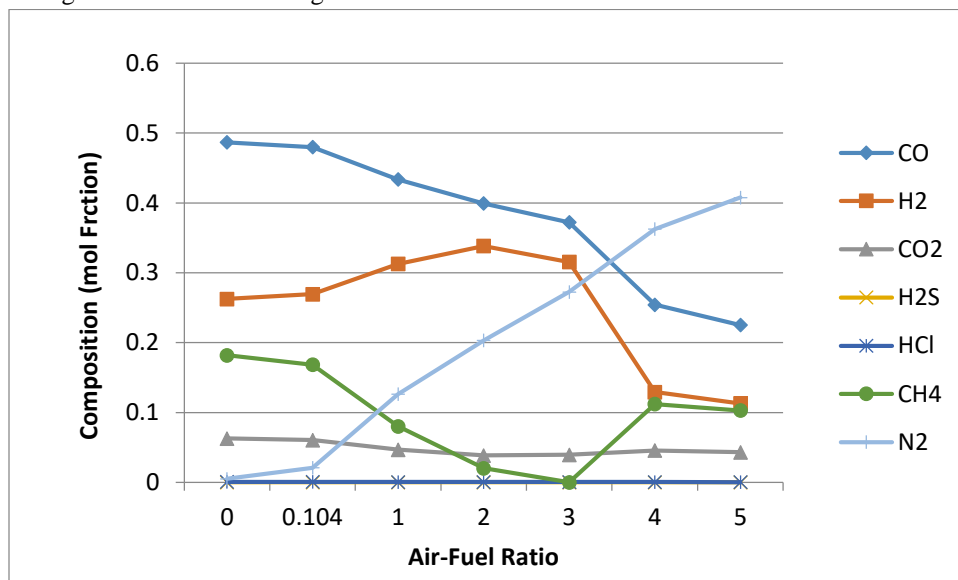


Fig.5: Effect of Air-Fuel Ratio on Syngas Composition

The simulation model has been validated and compared with both experimental data and simulation results from Nikoo and Mahinpey (2008) and Ajaree *et al.*, (2017). It was observed that the Aspen Hysys mode of this work is in good agreement with the experimental data and simulation results in the literature.

V. CONCLUSION

A computer simulation model of a fluidized bed biomass gasifier for OPF was developed using Aspen Hysys. Simulation of the processes, including chemical reactions

and mass/heat balance was carried out on each unit operation. A steady-state equilibrium method was used. This models OPF as a hypothetical component and was processed through a set of conversion and equilibrium air steam gasification reaction to obtain synthesis gas. The effects of gasifier temperature, steam to biomass ratio and air fuel ratio on the composition of the synthesis gas were analyzed. The results obtained from the sensitivity analysis are in good agreement with published work. The following are the important results achieved from the simulation:

1. Increase in temperature improves the gasification process. Hydrogen and carbon monoxide composition increases remarkably with increasing gasification temperature. Meanwhile, methane and carbon dioxide decreases.
2. Hydrogen and carbon monoxide decreases with increasing amount of air, while the volume of inert gas Nitrogen in syngas increases.
3. High steam to biomass ratio increases the concentration of hydrogen and methane, though more carbon monoxide is produced.
4. The optimum operating conditions were found to be: ER= 0.1-0.104 and gasification temperature 850 - 940°C.
5. Steam has better reactivity than fuel bound moisture. So, proper pretreatment of the feedstock like drying helps the gasification process.

From this study, it has reasonably shown that OPF from its proximate and ultimate analysis as a good potential source of synthesis gas. In a developing country like Nigeria, where the climatic conditions favors the growth of oil palm frond. The environmental impact of global warming as a result of the reference substance CO_2 will be drastically reduced if this biomass feedstock is potentially harnessed. The development of energy from biomass which is renewable remains the best as it provides a safer and clean environment than fossils fuels which are finite in nature.

REFERENCES

- [1] IPCC (2007). Inter-governmental panel on climate change 2007. The physical science basis contribution of working Group 1 to the fourth Assessment Report of the Intergovernmental Panel on climate change.
- [2] Nzegbule E.C (2008). Climate change adaptation and mitigation in tropical landscape. Proceedings of the 32nd Annual conference of Forestry Association of Nigeria (FAN). 21-23 October, 2008. Pp. 453-460.
- [3] Maniatis K, Guiu G, Riesgo J.(2002). The European commission perspective in biomass and waste thermochemical conversion. In: Bridgewater AV, editor. Pyrolysis and gasification of biomass and waste, Proceedings of an Expert Meeting. 2002. p. 1–18.
- [4] Brown ,S., Iverson, L.R and Liu, D (1993). Geographical distribution of carbon in biomass and soils of tropical Asian forests. *Geocarto international* 8:45-60.
- [5] Lin Y, Tanaka S.(2006) Ethanol fermentation from biomass resources: current state and prospects. *Appl Microbiol Biotechnol* 2006;69:627–42.
- [6] Caputo A.C, Palumbo M, Pelagagge PM, Scacchia F.(2005). Economics of biomass energy utilization in combustion and gasification plants: effects of logistic variables. *Biomass Bioenergy* 2005;28:35–51.
- [7] Yoshioka T, Hirata S, Matsumura Y, Sakanishi KW. Biomass resources and conversion in Japan: the current situation and projections to 2010 and 2050. *Biomass Bioenergy* 2005;29:336–46.
- [8] Mehrdokht B.Nikoo, Nader Mahinpey,(2008) Simulation of biomass gasification in fluidized bed reactor using ASPEN PLUS BIOMASS AND BIOENERGY 32 (2008)1245–1254
- [9] Faaij APC. Bio-energy in Europe: changing technology choices. *Energy Policy* 2006;34:322–42.
- [10] Sadaka S,Ghaly AE, Sabbah MA.(2002). Two phase biomass air-steam gasification model for fluidized bed reactors: PartI-model development. *Biomass and Bioenergy*2002;22:439–62.
- [11] Rauch R.(2003). Biomass gasification to produce synthesis gas for fuels and chemicals report made for IEA Bioenergy Agreement, Task 33: Thermal Gasification of Biomass;2003.
- [12] Carlos L.(2005) High temperature air/steam gasification of biomass in an updraft fixed bed type gasifier. PhD thesis. Stockholm, Sweden: Royal Institute of Technology, Energy Furnace and Technology;2005.
- [13] Reed T B, Das A.(1988). Handbook of biomass downdraft gasifier engine systems. Colorado: Solar Energy Research Institute; 1988.
- [14] Puig-Arnavat Maria , Joan Carles Bruno , Alberto Coronas (2010). Review and analysis of biomass gasification models *Renewable and Sustainable Energy Reviews* 14 (2010) 2841–2851
- [15] Knoef Ham (2005). Handbook biomass gasification. Meppel, The Netherlands: BTG Biomass Technology Group B.V.; 2005.
- [16] Khiyami M, Masmali I, Abu-khuraiba M (2008). Composting a mixture of date palm wastes, date palm pits, shrimp and crab shell wastes in vessel system. *Saudi J Biol Sci* 2008;15(2):199–205.
- [17] M. Bassyouni, Syed Waheed ul Hasan, M.H. Abdel-Aziz, S.M.-S. Abdel-hamid Shahid Naveed Ahmed Hussain , Farid Nasir Ani (2014). Date palm waste gasification in downdraft gasifier and simulation using ASPEN HYSYS *Energy Conversion and Management* 88 (2014) 693–699.
- [18] Basu P.(2010). Chapter 5 – gasification theory and modeling of gasifiers. In: Basu P, editor. Biomass gasification and pyrolysis. Boston: Academic Press; 2010.
- [19] Ersoz A, Ozdogan S, Caglayan E, Olgun H (2006). Simulation of biomass and/or coal gasification systems integrated with fuel cells. *J Fuel Cell Sci Technol (Trans ASME)* 2006;3(4):422–7.
- [20] Nieto C, Arenas E, Arrieta A, Zapata Z, Londono C, Valdes C, (2008). Simulation of IGCC technologies: influence of operational conditions (environmental and fuel gas production). *Rev Energetica* 2008;40:39–52.

- [21] Puig-Arnavat M. (2011). Performance Modelling Validation OF Biomass Gasifiers For Trigeneration Plants, unversitat Rovira I Virgil I, (2011).
- [22] Laihong Shen_, Yang Gao, Jun Xiao Simulation of hydrogen production from biomass gasification in interconnected fluidized beds B IOMASS AND B I O E N E R G Y 32 (2008) 120 – 127
- [23] P Basu (2010). Biomass Gasification and Pyrolysis: Practical Design and Theory; Associated Press for Elsevier Inc.,U.K, 2010.
- [24] P. Basu, (2006). Combustion and Gasification in Fluidized Beds. Taylor & Francis, pp. 355– 357.
- [25] Bemgba Bevan Nyakuma, Anwar Johari, Arshad Ahmad, Tuan A. T. Abdullah, Mojtaba Mazangi (2012). Design of a Bubbling Fluidized Bed Gasifier for the gasification of palm waste. *Jurnal Teknologi (Sciences & Engineering)* 58 (2012) 85–88
- [26] Demirbas A. (2008). Biofuels: Securing the Planet’s Future Energy Needs; Green Energy and Technology, Springer,2008.
- [27] Higman C. and M. Burgt van der. (2008). Gasification. 2nd Ed. Gulf Professional Publishing, (Elsevier), USA.
- [28] Doherty W, Reynolds A, Kennedy D (2009). The effect of air preheating in a biomass CFB gasifier using ASPEN Plus simulation. *Biomass Bioenergy* 2009;33 (9):1158–67.
- [29] Akunuri NV (1999). Modeling the performance, emissions, and costs of texaco gasifier-based integrated gasification combined cycle systems. M. Sc. thesis. Civil Engineering. North Carolina State University; 1999.
- [30] Suwanwarangkul R, Croiset E, Pritzker MD, Fowler MW, Douglas PL, Entchev E.(2007) Modelling of a cathode-supported tubular solid oxide fuel cell operating with biomass-derived synthesis gas. *Journal of Power Sources* 2007;166:386–99.
- [31] Zhu Y (2004). Evaluation of gas turbine and gasifier-based power generation system. PhD thesis. Civil, Construction, and Environmental Engineering. North Carolina State University; 2004.
- [32] Ajaree Suwatthikul Siripong Limprachaya , Paisan Kittisupakorn and Iqbal Mohammed Mujtaba (2017). Simulation of Steam Gasification in a Fluidized Bed Reactor with Energy Self-Sufficient Condition. *Energies* 2017, 10, 314; doi:10.3390/en10030314
- [33] Kaushal, P, Tyagi, R.(2017). Advanced simulation of biomass gasification in a fluidized bed reactor using ASPEN PLUS. *Renewa. Energy* 2017, 101, 629–636. [CrossRef]
- [34] Latif, A (1999). A Study of the Design of Fluidized Bed Reactors for Biomass Gasification; University of London: London, UK, 1999.
- [35] Arpit Shukla and Dr. Sudhir Y Kumar (2017). A Comparative study of Sugarcane Bagasse gasification and Direct Combustion. *International Journal of Applied Engineering Research* ISSN 0973-4562 Volume 12, Number 24 (2017) pp. 14739-14745
- [36] Anis Atikah Ahmad, Norfadhila Abdullah Zawawi, Farizul Hafiz Kasim, AbrarInayat b, Azduwin Khasri (2016). Assessing the gasification performance of biomass: A review on biomass gasification process conditions, optimization and economic evaluation *Renewable and Sustainable Energy Reviews* 53(2016)1333–1347
- [37] McKendry, P. (2002). Energy production from biomass (Part 3): gasification technologies. *Bioresource technol*; 83: 55 – 63.