International journal of Engineering, Business and Management (IJEBM) *[Vol-4, Issue-1, Jan-Feb, 2020]*
https://dx.doi.org/10.22161/ijebm.4.1.2 ISSN: 2456-7817

Fundamental Review and Analysis of Gasifier Performance and Gasification Model

Ugwuodo C.B[1*], Ugwuoke E.C[3], Owabor C.N[2] and Ogbeide S.E[2]

[1]Michael Okpara University of Agriculture Umudike, Umuahia, Abia State, Nigeria.
[2]Chemical Engineering University of Benin, Benin, Edo State, Nigeria.
[3]Projects Development Institute (PRODA), Enugu, Nigeria.

***Abstract*— A reliable, affordable and clean energy supply is of major importance for society, economy and the environment. The modern use of biomass is considered a very promising clean energy option for reduction of greenhouse gas emission and energy dependency. Biomass gasification has been considered as the enabling technology for modern biomass utilization. However, challenges remains in biomass gasifier design and gasification model for viable commercial application through reliable model prediction and optimization of the process condition to obtain quality product compositions and maximal efficiencies. Bubbling fluidized bed gasifier and Apen Plus gasification model can salvage the undue complex processes and aims to develop the simplest possible model using the process simulator or Aspen Plus that incorporates the key gasification reaction and gasifier design.*

***Keywords*— Gasification; Biomass; Fluidized bed; Thermodynamic model; kinetic model; Aspen Plus.**

I. INTRODUCTION

The globe is shifting to renewable sources of energy owing to problems of global warming and climatic change. Apart from these challenges there is also huge concern over the depletion of fossil fuels in the near future and an increasing awareness of energy conservation have drawn worldwide attention (Zainal *et al.*,2000, Bassyouni *et al.*,2004). There are nine general sources of energy on earth. They are; solar, biomass, wind, wave, hydro, tidal, geothermal, nuclear and fossil. Geothermal, nuclear and fossil are non renewable sources of energy that depletes with time. Biomass, fuel derived from organic matter on a renewable basis is among the most promising renewable sources of energy. The wide spread of availability of biomass has been widely recognized, as it has potential to supply much larger amount of useful energy with fewer environmental impacts than non renewable sources (Puig-Arnavat *et al.*, 2010). Biomass can be transformed into commercial products via either biochemical or thermochemical processes (Lin and Tanaka, 2006). Although, biochemical transformation of biomass still faces challenges related to low economy and efficiency and also, it is not effective or feasible for any kind of application (*Basu*, 2010).

In alternative, the thermo chemical processes are effective and flexible. Combustion, pyrolysis and gasification are the three main thermochemical conversion methods. While combustion of biomass is the most direct and technically easiest process, the overall efficiency of generating heat from biomass energy is low (Kumar *et al.*,2009). Pyrolysis converts biomass into bio-oil in the absence of oxygen (O_2). The limited uses and difficulty in downstream processing of bio-oil have restricted the wide application of biomass pyrolysis technology (Faaij, 2006). Among the thermochemical conversion, gasification has many advantages over combustion and pyrolysis. Gasification is regarded as the most promising technology that can exploit the embedded energy within various kinds of biomass and converts them into valuable intermediates with flexibility for many industrial applications such as heat, electricity and liquid fuels (Chen *et al.*,2007). Gasification converts biomass through partial oxidation into a gaseous mixture, small quantities of char and condensable compounds. The composition of the gas mixtures and heating value are greatly dictated by gasifier design and type of gasifying agents. Among these, the fluidized bed gasifier is most effective due to its flexibility, temperature control, good gas- solid contact and mixing and high reaction rates. Air is also used as the gasifying agent due to simplicity and low cost operations. Utilization of biomass via gasification is a very important source of energy in many parts of the world, especially for areas remote from a supply of high quality fossil fuels, such as natural gas, liquefied petroleum gas (LPG), coal etc. (Zainal *et al.*, 2001). This review aims to further provide fundamental insight in gasifier design and gasification models for thermal gasification of biomass materials.

II. GASIFICATION PROCESS AND REACTIONS

Gasification is a technology used for transformation of biomass into a viable fuel and it is sandwich in between combustion and pyrolysis in a gasification unit. The conversion of biomass by gasification into a fuel suitable for various use ranging from production of chemicals, electricity and heating increases greatly to a large extent the potential usefulness of biomass as a renewable resource (McKendry, 2002). Gasification is a robust proven technology that can be operated either as a simple, low technology system based on a fixed bed gasifier, or as a more sophisticated system using fluidized bed technology (McKendry, 2002). Gasification is the conversion of biomass to a gaseous fuel by heating in a gasification medium such as air, oxygen or steam. This whole process is completed at elevated temperature range of 800 – 1300^{0}C (Lee *et al.*, 1998) with series of chemical reaction.

Gasification can be considered an upgrading process that takes in a solid which is difficult to handle, strip it of undesirable constituents and convert it into a gaseous product that can be handled with maximum convenience and minimum cost and can readily be purified to a clean fuel or feedstock for synthesis of other chemical (Faaij, 2006). Air gasification produces a poor quality gas with regard to the heating value which is around 4 – 7MJm^{-3} higher heating value (HHV) while O_2 and steam blown processes result in a syn-gas with a heating value in the range of 10 – 18 MJm^{-3} (HHV) (McKendry, 2002). However, gasification with pure O_2 is not practical for biomass gasification due to prohibitively high costs for O_2 production using current commercial technology (Cryogenic air separation).

The process of biomass gasification is represented by the reactions in Table 1. The gasification process can be split into three lined processes: pyrolysis, gasification and combustion. (Puig-Arnavat *et al.*, 2010; McKendry, 2002) represents gasification process in four stages; drying, devolatisation, oxidation and reduction. Drying is necessary because it will improve the physical and chemical characteristic of the biomass to aid in further conversion to biofuels.

The overall reaction in an air and/or steam gasifier can be represented by Equation 1, which proceeds with multiple reactions and pathways (Kumar, 2009). The heat of reaction for Equation (2-6) show that the greatest energy released is derived from the complete oxidation of carbon to carbon dioxide (Equation 3) i.e. combustion , while the partial oxidation of carbon to carbon monoxide accounts for only about 65% of the energy released during complete oxidation (McKendry, 2002). Unlike combustion that produces only a hot gas product, carbon monoxide, hydrogen and steam can undergo further reactions during gasification as represented by Equation (7 – 10).

Table 1: Gasification reactions (McKendry, 2002)

Reaction	Heat of reaction	Reaction name	
General reaction			
$CH_xO_4(biomass) + O_2(21\%\ of\ air)$ $+ H_3O\ (steam) \rightarrow CH_4 + CO$ $+CO_2 + H_2 + H_2O\ (unreacted\ steam)$ $+C\ (char) + tar$		Overall reaction	(1)
Heterogeneous reactions			
$C + {}^1\!/_2\,O_2 \leftrightarrow CO$	$(-111MJKmol^{-1})$	Partial oxidation	(2)
$C + O_2 \leftrightarrow CO_2$	$(-406MJKmol^{-1})$	Complete oxidation	(3)
$C + CO_2 \leftrightarrow 2\,CO$	$(+172MJKmol^{-1})$	Boudard	(4)
$C + H_2O \leftrightarrow CO + H_2$	$(+131\ MJKmol^{-1})$	Water gas	(5)
$C + 2H_2 \leftrightarrow CH_4$	$(-75\ MJKmol^{-1})$	Methanation	(6)
Homogenous reactions			
$CO + {}^1\!/_2\,O_2 \rightarrow CO_2$	$(-283MJKmol^{-1})$	CO Partial combustion	(7)
$H_2 + {}^1\!/_2\,O_2 \rightarrow H_2O$	$(-242\ MJKmol^{-1})$	H_2 partial combustion	(8)
$CO + H_2O \leftrightarrow CO_2 + H_2$	$(-41MJKmol^{-1})$	Water gas shift reaction	(9)
$CH_4 + H_2O \leftrightarrow CO + 3H_2$	$(+206MJKmol^{-1})$	Steam-methane reforming	(10)

Hydrogen sulphide (H_2S) and ammonia (NH_3) formation reactions

$H_2 + S \rightarrow H_2S$ Not reported $H_2S\ formation$ (11)

${}^{1}/_{2}\, N_2 + {}^{1}/_{2}\, H_2 \leftrightarrow NH_3$ $NH_3\ formation$ (12)

III. EVALUATION AND PERFORMANCE OF BIOMASS GASIFIER

Gasifiers are of two types, fixed bed and fluidized bed with alternative form within each type (Rampling, 1993; Rampling and Gill, 1993). Cost of manufacturing is related to fabrication complexity and materials used, while ease of operation is the easiness to handle the gasifier during gasification process (Reed and Das, 1988; Kythavone, 2007).

The performance of biomass gasifiers could be characterized by several parameters such as fuel composition, gasifying medium, operating pressure, temperature, moisture content of the fuels, gasifier design (mode of bringing the reactants into contact inside the gasifier), producer gas/synthesis gas composition which directly influences the heating value of the gas and gasification efficiency.

Table 2: Comparative evaluation of different designs of biomass gasifers (Kishore, 2008; Brigdewater, 1995 and Beenakers, 1999)

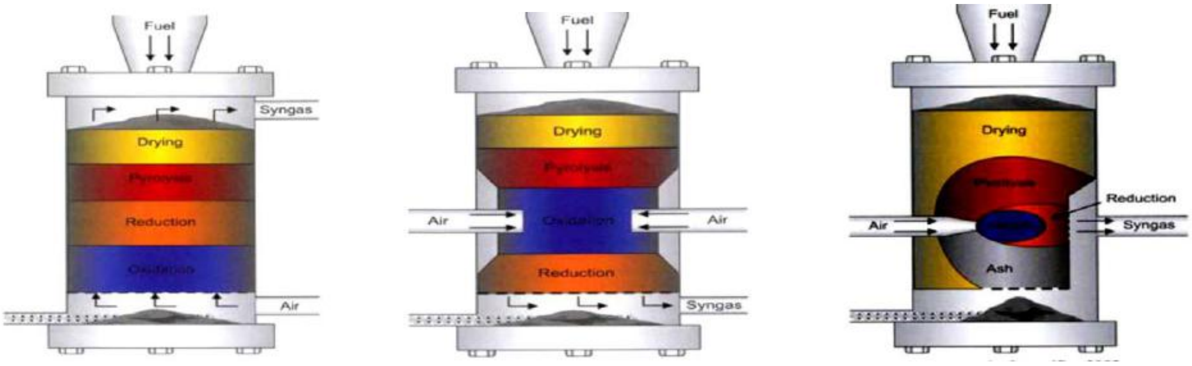
Downdraft	**Updraft**
Simple and proven technology	Simple and proven technology
Suitable for biomass with low moisture	Low exit gas temperature
Producer gas with moderate calorific value and low tar and ash (or particular) content	High thermal efficiency
Feed and air mover in the same direction	Calorific value but high tar and ash (or particulate) content
High exit gas temperature	High residence time of solids
Suitable for capacities of 20 – 200kw	High overall carbon conversion
High residence time of solids	Extensive gas clean up required before it can be used in engines
High overall conversion carbon conversion	Suitable for capacities up to 250kw
Limited scale up potential with maximum capacity of 250kw	Limited scale up potential
Bubbling fluidized bed	**Circulating fluidized bed**
High fuel flexibility in terms of both size and type	High fuel flexibility in terms of both size and type
Flexibility of operation at loads lower than design load	Flexibility of operation at loads lower than design load
Ease of operation	Ease of operation
Low feedstock inventory	Low feedstock inventory
Good gas-solid contact and excellent mixing	Good temperature control and high reaction rates
In-bed catalytic processing possible	In-bed catalytic processing possible
Producer gas with moderate HHV but low tar levels and high particulates	Producer gas with moderate tar levels but high particulates
Carbon loss with ash	High carbon conversion
High conversion efficiency	Good gas-solid contact and excellent mixing
Suitable for large-scale capacities (up to 1Mw or even higher)	Suitable for large-scale capacities (up to 1mw or even higher)
Good scale-up potential	High conversion efficiency
	Very good scale-up potential

Entrained flow bed	**Twin fluidized bed**
Relatively complex construction and operation	Relatively complex construction and operation
Fuel specificity in terms of particle size (costly feed preparation)	Producer gas with moderate HHV and moderate tar levels
Low feed stock inventory	Cleaning of gas required before it can be fired into engines
High temperature gives good gas quality	In-bed catalytic conversions possible
Problems with construction materials at high temperature	Good-gas solid contact and mixing
Good-gas solid contact and mixing	Relative low efficiency
Producer gas with moderate HHV and low tar content	Suitable for high specific capacities (>1mw)
High conversion efficiency	Good scale-up potential but relatively complex design
Suitable for high capacities (>1mw)	
Very good scale-up potential	

Table 2 shows comparative evaluation of different design of biomass gasifier. This is why it is very difficult to predict the exact composition of the gas from a gasifier (Basu, 2006). The fixed bed gasifier has been the traditional process used for gasification, operated at temperatures around 1000^0C. Depending on the direction of airflow, the gasifier are classified as updraft, downdraft or cross flow (McKendry, 2002). In the updraft gasifier, the feed (biomass) is introduced from the top and moves downwards while gasifying agents (air, steam, etc) are introduced at the bottom of the grate, so the product moves upwards. In this case the combustion takes place at the bottom of the bed which is the hottest part of the gasifier and product gas exits from the top at lower temperature (around 500^0C). Because of the lower exit temperature, the product gas contains large amount of tar. In a downdraft gasifier, both the feed and product gas moves downward and the product exits from the bottom at a higher temperature (around 800^0C – 1000^0C). In this case most tars are consumed because the gas flows through a high temperature region. In a cross flow gasifier the feed moves downwards while the air is introduced from the side, the gases being withdrawn from the opposite side of the unit at same level. A hot combustion/gasification zone forms around the entrance of the air, with the pyrolysis and drying zones being formed higher up in the vessel. Ash is removed at the bottom and the temperature of the gas leaving the unit is about 800 - 900^0C, as a consequence thus gives a low overall energy efficiency for the process and a gas with high tar content (Mckendry, 2002).

In the fluidized bed gasifier, the feed is introduced at the bottom, which is fluidized using air, nitrogen and/or steam and the product gas then move upward. There are more particulates in the product gas from this gasifier (Cifeno, 2002). Fluidization of the bed enhances the heat transfer to the biomass particles leading to increases in reaction rates and conversion efficiencies. Fluidized beds also are able to tolerate a wide variation in fuel types and their characteristics. A fluidized bed can be either a bubbling fluidized bed or a circulating fluidized bed. In case of the bubbling fluidized bed gasifier, the flow rate of the fluidizing agent is comparable to the minimum fluidizing velocity. Uniform temperature across the bed can be maintained by fluidization resulting in uniform product gases. The fluidizing medium used are generally sand, silica or alumina materials which have high specific heat capacity and can operate at high temperature. Circulating fluidized beds have higher flow rates of the fluidizing agents which move most of the solid and ungasified particles to an attached cyclone separator, from which solids are re-circulated to the gasifier bed. The higher flow of gasifying agent increases the heat transfer and conversion rate of the biomass. Figure 1 and Figure 2 shows a schematic diagram of different types of gasifier.

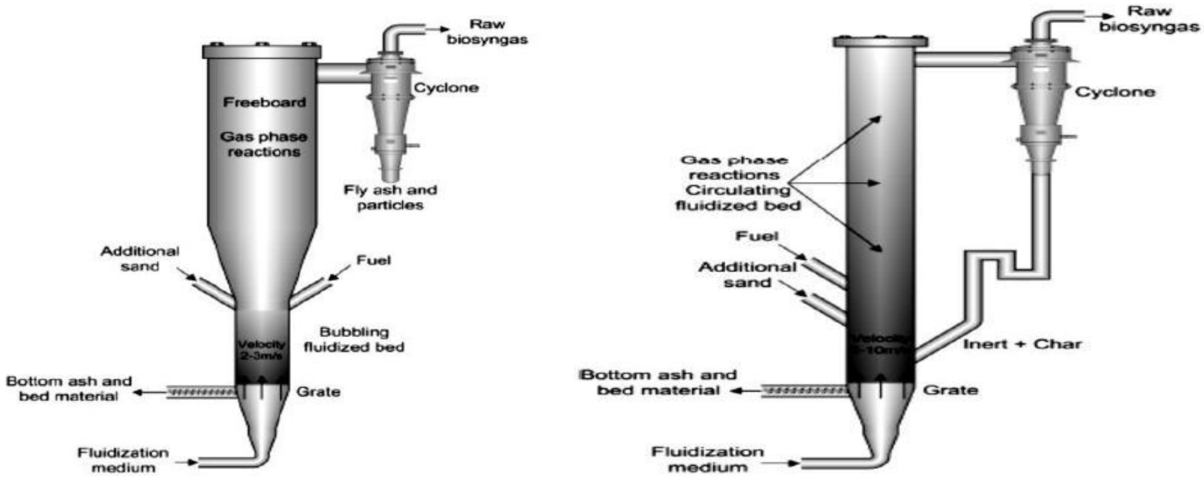
FIXED BED



(a) Updraft *(b) Down-draft* *(c) Cross-flow*

Fig.1: Schematic diagram of fixed bed gasifiers(PUIG-ARNAVAT, 2011)

FLUIDIZED BED



(a) Bubbling *(b) Circulating*

Fig.2: Schematic diagram of fluidized bed gasifiers

Table 3 shows the average syngas composition (vol. %) of different feed stock and their operating conditions of single throat down draft gasifier.

Table 3: Average syngas composition (vol. %) of different feed stock and their operating conditions of single throat down draft gasifier.

Feedstock type	HHV (MJ/kg)	Gasifying medium	Equivalent ration	Average syngas composition vol. % CO CO_2 CH_4 H_2				Syngas (MJ/Nm^3)	Gas yield (Nm^3/kg)	Carbon conversion efficiency (%)	Cold gas efficiency	Source
				CO	CO_2	CH_4	H_2					
Oil palm fronds	17.28	Unheated air	0.27	22.78	11.81	2.02	8.47	4.66	1.91	74.4	51.6	Fisecha *et al.*, 2012
		Preheated air	0.22	24.94	12.80	2.03	10.53	5.31	1.94	93.0	59.6	Fisecha *et al.*, 2012

Wood clips	20.50	Ambient air	0.35	23.8	13.51	2.6	13.50	5.77	na	na	Na	Olgun *et al.*,2010
Pelletized bagasse 6mm	17.93	Ambient air	0.27-0.30	23.30	11.40	2.80	9.90	5.32	na	na	Na	Erlich&Fransson (2011)
Pelletized wood 6mm	20.27	Ambient air	0.28-0.30	25.70	9.90	2.60	11.90	5.80	2.0-2.1	na	Na	Erlich&Fransson (2011)
Pelletized empty fruit bunch EFB 6mm	18.05	Ambient air	0.23-0.37	17.00	14.50	1.90	13.50	4.63	1.8-2.1	na	Na	Erlich&Fransson (2011)
Pelletized empty fruit bunch EFB 8mm	18.05	Ambient air	0.34-0.43	17.40	13.70	1.50	12.90	4.44	2.1-2.5	na	Na	Erlich&Fransson (2011)
Residual eucalyptus wood	18.14	Ambient air	0.35	17.34	na	1.79	16.70	5.04	na	na	Na	Martinez *etal.*, (2011)

na, not available

Some authors, like Prins *et al.*, 2007, Ptansinki *et al.*, 2007 and Ptansinki, 2008 , have focused their studies on the efficiency of biomass gasification. Efficiency is either based on energy (lower heating value, LHV) (Equation 13) or exergy (chemical and physical) (Equation 14). All efficiencies are defined as the ratio between the exergy (energy, respectively) of the syngas to the exergy (energy, respectively) of the biomass.

Energy efficiency (%) (per kg of biomass): $\eta = \frac{\eta_{gas} \cdot LHV_{gas}}{LHV_{biomass}}$ (13)

Exergy efficiency (%) (for an adiabatic gasifier using air as the gasifying agent: $\psi = \frac{\eta_{gas} \cdot (e_{ch.gas} + e_{ph.gas})}{e_{ch.biomass} + \eta_{air} \cdot e_{air}}$ (14)

where η_{gas} is the molar amount of product gas (kmol); η_{air} is the molar amount of air (kmol); $e_{ch.gas}$ is the chemical exergy ofproduct gas (kJ/kmol); $e_{ph.gas}$ is the physical exergy of product gas (kJ/kmol); $e_{ch.biomass}$ is the chemical exergy of biomass (kJ/kmol); e_{air} is the specific molar exergy of air (kJ/kmol). Ptasinski, 2008 analysed the efficiency of biomass gasification using the triangular C-H-O diagram, considering a biomass fuel that can be represented by a general formular of $CH_{1.4}O_{0.59}N_{0.0017}$. At the equivalence ratio of 0.2, the chemical and total exergy of the gas reach the maximum at the carbon boundary. The carbon boundary point (CBP) is the optimum point for operating an air blown gasifier and it is obtained when exactly enough gasifying medium is added to avoid carbon formation and achieve complete gasification. Desrosiers, 1979; Double and Bridgwater 1985 proved that the CBP is the optimum for gasification with respect to energy based efficiency and Prin *et al.*, 2007 proved that it is the optimum point with respect to exergy based efficiency, as cited by Ptansinki *et al*., 2007

IV. BIOMASS GASIFICATION MODELS

Gasification process involves numerous complex chemical reactions. Different process variables considered in gasification process and chemical equation requires development of a mathematical models. The main objectives of these models are to study the thermochemical processes during the gasification of the biomass and to evaluate the influence of the main input variables such as moisture content, air/fuel ratio, producer-gas composition and the calorific value . Some studies only consider the final composition of chemical equilibrium while others take into account the different processes along the gasifier, distinguishing at least two zones, free board and reactor chamber. The models can be divided into kinetic rate models, thermodynamic equilibrium models and neural network model. Some models use the process simulator Aspen Plus combining thermodynamic and kinetic rate models.

4.1 KINETIC RATE MODELS

Kinetic model provide essential information on kinetic mechanisms to describe the conversion during biomass gasification which is crucial in designing, evaluating and improving gasifiers. These rate models are accurate and detailed but are computationally intensive. Kinetic models describe the char reduction process using kinetic rate expressions obtained from experiments and permit better simulation of the experimental data while the residence time of gas and biomass is relatively short.

4.2 THERMODYNAMIC RATE MODELS

Thermodynamic models use equlibrium calculations which are independent of gasifier design. At chemical equilibrium, a reacting system is at its most stable composition, a condition achieved when the entropy of the system is maximised while its Gibbs free energy is minimized. Two thermodynamic models were developed: a one compartment model, where the hydrodynamic complexity of the fluidized bed gasifier was neglected and an overall equilibrium approach was used; and a two compartment model, where the complex hydrodynamic conditions presented within the gasification chamber were taken into account. The models were capable of predicting the reactor temperature, gas composition, gas higher heating value, and overall carbon conversion under various operating conditions, including bed height, fluidization velocity, equivalence ratio, oxygen concentration in the fluidizing gas and rice husk moisture content. Because of the large amount of volatile material in biomass and the complexity of biomass reaction rate kinetics in the fluidized beds, the author ignored char gasification and simulated the gasification process by assuming that biomass gasification follows the Gibbs equilibrium. The reactions considered in the development of the model were pyrolysis, partial combustion and gasification. Predictions of the core, annulus and exit temperatures, as well as the mole fractions of the combustible gas components and product gas higher heating value agreed reasonably well with experimental data (Puig-Arnvat *et al.*, 2010).

4.3 ASPEN PLUS GASIFICATION MODELS

Some authors, trying to avoid complex processes, and develop the simplest possible model that incorporates the principal gasification reactions and the gross physical characteristics of the reactor, have developed model using the process simulator Aspen Plus (Aspen Plus Tech, 2006). Aspen plus is a problem oriented input program that is used to facilitate the calculation of physical, clinical and biological processes, it can be used to describe processes involving solids in addition to vapour and liquid streams. Aspen Plus makes model creation and updating easier, since small sections of complex and integrated systems can be created and tested as separate modules before they are integrated. Thus, process simulator is equipped with a large property data bank containing the various streams in a gasification plant, with an allowance for the addition of in-house property data. Where more sophisticated block abilities are required, they can be developed as FORTRAN subroutines.

When model are developed for a gasification reactors it is assumed that the gasifier consist of four zones with different physical and chemical processes taking place. They are the zones for (i) Biomass/coal preheating and drying, (ii) Pyrolysis, (iii) Gasification and (iv) Combustion, followed by ash layer, which acts as a preheater of the reacting gases.

The ASPEN PLUS process simulator has been used by different investigators to simulate coal conversion; examples include methanol synthesis (Kundsen *et al.*,1982, Schwint,1985), indirect coal liquefaction processes (Barker, 1983), integrated coal gasification combined cycle (IGCC) power plants (Philip *et al.*, 1986, Puig-Arnavat *et al.*, 2010), coal hydrogasification processes (Backham *et al.*, 2003) and coal gasification simulation (Lee *et al.*, 1992). It has also been used to model and simulate a tyre pyrolysis until within a gasification based plant (Gomez *et al.*2007)). However, the work that has been done on biomass gasification is less extensive. Mansaray *et al.,*(2000) used Aspen Plus to simulate a dual – distributor type fluidized bed rice husk gasifier based on material balance, energy balance and chemical equilibrium relations.

Nikoo and Mahinpey (2008), developed a model capable of predicting the steady state performance of an atmospheric fluidized-bed gasifier by considering the hydrodynamic and reaction kinetics simultaneously. They used four Aspen Plus reactor models and external FORTRAN subroutines for hydrodynamic and kinetics nested to simulate the gasification process as shown in Figure 3.

Other authors have worked with Aspen Plus to model the gasification process for coal and biomass. Yan and Radolph (2000) , developed a model for a compartmented fluidized bed coal gasifier process, Sudiro *et al.,(2009)* modeled the gasification process to obtain synthetic natural gas from petcoke. Paviet *et al*.,(2009) describe a very simple two-step model of chemical equilibrium in wood biomass gasification process. Robinson and Luyben (2008), presented an approximate gasifier model that can be used for dynamic analysis using Aspen Dynamics.

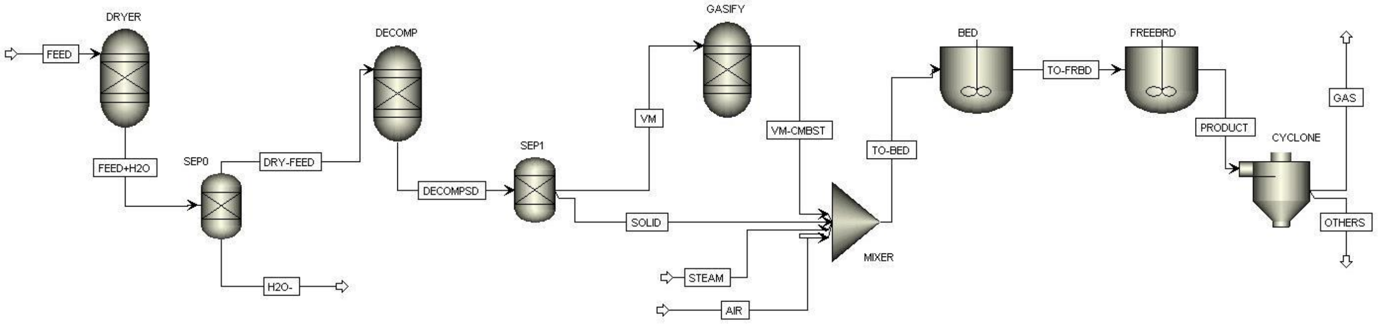


Fig.3: Advanced System for Process Engineering (Aspen) Plus simulation flowsheet (Puig-Arnavat et al., 2010).

They used a high molecular weight hydrocarbon that is present in the Aspen Library as a pseudo fuel and the proposed approximate model captured the essential macroscale thermal, flow, composition and pressure dynamics.

4.4 ARTIFICIAL NEURAL NETWORK GASIFICATION MODEL

Artificial neural networks (ANNs) have been applied in few references for modeling biomass gasification process in fluidized bed (Yochioka *et al.*,2005; Faaij, 2006). It has been extensively use in the fields of pattern recognition, signal processing, function approximation and process simulation (Guo *et al.*, 2001; Brown *et al.*, 2006; Puig-Amavat *et al.*, 2009). ANNs are useful when the primary goal is outcome prediction and important interactions of complex non linearity's exist in a data set like for biomass gasification, because they can approximate arbitrary non linear functions. One of the characteristics of modeling based on artificial neural networks is that it does not require the mathematical description of the phenomena involved in the process and might therefore prove useful in simulating and up-scaling complex biomass gasification process. Guo *et al.*, (2001), developed a hybrid neural network model to predict the product yield and gas competition of biomass gasification in an atmospheric pressure steam fluidized bed gasifier. They used as input variables the bed temperature and the stock residence time. Taking into account only these two input variables, forced the authors to develop four ANNs, one for each biomass feedstock considered. Even the results showed that the ANNs developed could reflect the real gasification process. It would have been more interesting to develop just one but more general model for the biomass gasifier in study and accounting for different biomass feedstocks. Brown *et al.*,(2006), developed a reaction model for computation of products compositions of biomass gasification in an atmospheric air gasification fluidized bed reactor. They combine the use of an equilibrium model and ANN regressions for modeling biomass gasification process. Their objective was to improve the accuracy of equilibrium calculation and prevent the ANN model from learning mass and energy balances, thereby minimizing the experimental data requirements. As a result, a complete stoichiometry was formulated and corresponding reaction temperature difference parameters computed under the constraint of the non-equilibrium distribution of gasification products determined by mass balance and data reconciliation. The ANN regressions related temperature differences to fuel composition and gasifier operating conditions.

V. CONCLUSION

With the increasing world demand for alternative energy source, declining petroleum reserves and quest for energy mix, there is a renewed interest in biomass gasification technology as a viable option for the production of producer/synthesis gas from renewable materials (biomass). Biomass gasification is a promising technology to displace use of fossil fuels and to reduce CO_2 emission. However, challenges remain in the biomass gasification for viable commercial application through proper evaluation of gasifier designs and of gasification models for reliably prediction and optimization of the process to obtain maximum efficiencies. Different types of gasifier designs have been evaluated (fixed bed, updraft, downdraft, cross draft and fluidized bed, bubbling fluidized and circulating fluidized bed. Among all these gasifier, bubbling fluidized gasifier enhances the heat transfer to the biomass particle leading to increase in reaction rates and conversion efficiencies. It also provides a uniform product gases since uniform temperature across the bed can be maintained by fluidization. Gasification models helps to predicts the composition of product gases. Several different types have been developed such as kinetic, equilibrium artificial neural networks and Aspen Plus gasification models. Aspen gasification model provides the simplest and easier way of developing a model that integrate the basic reactions and hydrodynamic features of the reactor.

REFERENCES

[1] Ajay, K., David, J., and Milford, H. (2009). Thermochemical Biomass Gasification: A review of the current status of the technology. Energies 2; 556 – 581.

[2] Basu, P. (2006). “Combustion and gasification in fluidized beds”. London: Taylor and Francis Group/CRC Press.

[3] Beenackers, A. A. (1999). “Biomass gasification in moving beds. A review of European technologies. Renew Energy; 16: 1180 – 6.

[4] Bridgwater, A. V. (1995). “The technical and economic feasibility of biomass gasification for power generation”. Fuel; 74: 631 – 53.

[5] Brown D, Fuchino T, Marechal, F (2006). “Solid fuel decomposition modeling for the design of biomass gasification systems”. In: Marquardt W, Pantelides C, editors. Proceedings of the 16th European Symposium on computer aided process engineering and 9th international symposium on process systems engineering. P:1661-6.

[6] Cifemo, J. P. and Marano, J. J. (2002): “Benchmarking biomass gasification technologies for fuels, chemicals and hydrogen production”. USDOE National Energy Technology Laboratory; Pittsburgh, P. A. USA.

[7] Desrosiers, R. (1979). “Thermodynamics of gas char reactions”. In: Reed T B, editor. A survey of biomass gasification. Colorado: Solar Energy Research Institute.

[8] Double, J. M. and Bridgwater, A. V. (1985). “Sensitivity of theoretical gasifier performance to system parameters”. Energy from biomass, proceedings of the third E. C. conference.

[9] Erlich, C. and Fransson, T. H. (2011). “Downdraft gasification of pellets made of wood, palm oil residues respective bagasse: experimental study”. Applied energy 88 (3), 899 – 908.

[10] Fisecha, M., Shaharin, A. S., Anita, R. (2012). Gasifier selection, design and gasification of oil palm fronds with preheated and unheated gasifying air. Bioresource Technology; 126: 224 – 232.

[11] Gil, J., Corella, J., Aznar, M. P. and Caballero, M. A. (1999). Biomass gasification in atmospheric and bubbling fluidized bed: effect of the type of gasifying agent on the product distribution. Biomass Bioenergy; 17: 389 – 403.

[12] Guo B,Li D, Cheng C, Lu Z, Shen Y. (2001). “Simulation of biomass gasification with a hybrid neural network model”. Bioresour Technol :76(2):77-83.

[13] Kishore, V. N., editor (2008). “Renewable energy engineering and technology: a knowledge compendium”. New Delhi.

[14] Martinez, J. D., Silva, E. E., Andrade, R. V. and Jaen, R. L. (2011). Experimental study on biomass gasification in a double air stage downdraft reactor. Biomass and Bioenergy 35, 3465 – 3480.

[15] Mckendry, P. (2002). Energy production from biomass (part 1): overview of biomass. Bioresour Technol; 83: 37 – 46

[16] McKendry, P. (2002). Energy production from biomass (Part 3): gasification technologies. Bioresource technol; 83: 55 – 63.

[17] Nikoo, M. B. and Mahinpey, N. (2008). Simulation of biomass gasification in fluidized bed reactor using ASPEN PLUS, Biomass Bioenergy, doi: 10.1016/j.biombioe:2008.02020.

[18] Olgun, H., Ozdogan, S. and Yinesor, G. (2010). Results with a bench scale downdraft biomass gasifier for agricultural and forestry residues. Biomass and bioenergy 35 (2011), 572 – 580.

[19] Paviet, F., Chazaren, F., and Tazerout, M. (2009). “Thermochemical equilibrium modeling of a biomass gasifying process using Aspen Plus”. Int. J. Chem. React Eng.: 7: A40.

[20] Puig-Arnavat M., Performance Modelling Validation OF Biomass Gasifiers For Trigeneration Plants, unversitat Rovira I Virgil I, (2011)

[21] Prins, M. J., Ptasinski, K. J., Janssen, F. G. (2007). From coal to biomass gasification: comparison of thermodynamic efficiency: energy; 32: 1248 – 59.

[22] Prins, M. J., Ptasinski, K. J., Janseen, F. G. (2003). Thermodynamic of gas-char reactions: first and second law analysis. Chem. Eng. Sci. %3: 1003 – 11.

[23] Prins, M. J., Ptasinski, K. J., Janssen, F. G. (2006). More efficient biomass gasification via torrefaction. Energy; 31” 3458 – 70.

[24] Ptasinki, K. J., Prins, M. J., Pierik, A. (2007). Exergetic evaluation of biomass gasification. Energy; 32(4): 568 – 74

[25] Ptasinki, K. J. (2008). Thermodynamic efficiency of biomass gasification and biofuels conversion. Biofuels Bioprod Bioref: 2: 239 – 53.

[26] Rampling, T. (1993). Fundamental research on the thermal treatment of waste and biomass: literature review on part research on thermal treatment of biomass and waste.

[27] Rampling, T. and Gill, P. (1993). Fundamental research on the thermal treatment of wastes and biomass: thermal treatment characteristics of biomass. ETSU B/TI/00208/Rep/2.

[28] Robinson, P. I. and Luyben, W. L. (2008). Simple dynamic gasifier model that runs in Aspen dynamic. Ind. Eng. Chem. Res. 47: 7784 – 92

[29] Sudiro, M., Zanella, C. M., Bressan, L., Fontana, M. and Bertucco, A. (2009). Synthetic natural gas (SNG) from petcoke; Model development and simulation. In: Proceedings of the 9th Internation conference on Chemical and Process Engineering (Icheap-9).

[30] Yan, H. M. and Rudolph, V. (2000). Modeling a compartmented fluidized bed coal gasifier process using Aspen Plus. Chem. Eng.; 183: 1 – 38.

[31] Zainal, Z. A., Rifau, A., Quadir, G. A., Seetharamu, K. N. (2002). Experimental investigation of a downdraft biomass gasifier. Biomass Bioenergy; 23: 283 – 9.