International Journal of Advance Research in Science and Engineering
Vol. No.5, Issue No. 04, April 2016
www.ijarse.com
IJARSE
ISSN 2319 - 8354

PROCESS SIMULATION OF A ENTRAINED FLUIDIZED BED BIOMASS GASIFICATION USING ASPEN PLUS

S.Ilaiah[1], D.Veerabhadra Sasikanth[2], B.Satyavathi[3]

[1,2]University College of Technology, Osmania University, Hyderabad,(India)

[3]Indian Institute of Chemical Technology, Hyderabad,(India)

ABSTRACT

Due to the environmental and price issues of current energy crisis, scientists and technologists around the globe are intensively searching for new environmentally less-impact form of clean energy that will reduce the high dependency on fossil fuel. In the near future biomass gasification is likely to play an important role in energy production and conversion. Its application has great potential in the context of climate change mitigation, increasing efficiency and energy security. The gasification of the biomass, karanjacake produces synthesis gas (syngas) in which CO and H_2 are the essential components. The composition of produced gas depends on the types of gasifier and the gasification conditions among others. This work is developed by using the model of biomass gasification in an entrained fluidized bed gasifier using the ASPEN PLUS simulator. The Gibbs free energy minimization method was used to predict the composition of the produced gas. The influence of operating conditions as temperature (700-1500°C), equivalence ratio (ER) (oxygen/biomass ratio) (0.2 to 0.50), steam-to-biomass ratio (0.2-1),Pressure (1-80 bar) were varied over a wide range on gasifier performance are investigated.The optimal reaction temperature is considered to be 1227°C and the optimal equivalence ratio is 0.225 in that the low heating value of the produced gas, carbon conversion and cold gas efficiency achieve their maximum values. Higher temperature was beneficial to lower the amount of tar.The introduction of oxygen to the gasifier strengthened the gasification and improved the carbon conversion, but lowered the lower heating value and the H2/CO ratio of the syngas. The optimal oxygen/biomass ratio in this study was 0.225. With steam addition, the produced gas yield and in particular the H2 yield increased gradually, while the CO yield decreased slowly. The optimal steam /biomass ratio in this study was 0.45.Therefore, the developed model in this study provides a tool for design and optimization of a biomass Entrained fluidized bed gasifier.

Keywords: Biomass gasification,Aspen plus, Sensitivity analysis

I. INTRODUCTION

Biomass gasification coupled with other renewable energy options would cut dependency on imported energy and has great potential in the context of climate change mitigation, increasing efficiency and energy security and promote regional development as well as diversification by creating jobs and income in rural areas [1-2].

Gasification is a process for converting carbonaceous materials to a combustible or synthetic gas [3] using a gasifying agent such as oxygen or air and/or steam. Although gasification is a relatively old process, the versatility of the process (with production of syngas, electricity, hydrogen, or chemicals) and the multiplicity of technological solutions (fixed beds, moving beds, fluidized beds, and entrained flow reactors) make it a current topic of investigation. As one of the attempt to study performance of gasifier with air as gasifying agent, an equilibrium model based on minimization of Gibbs free energy was developed for rubber wood and syngas composition obtained by Paviet et al.[6].This technology can use different reactors, including fixed-bed (Hobbs et al., 1993), moveable-bed (Beenackers, 1999), fluidized-bed (Natarajan et al., 1998) and entrained-flow-bed reactors (Chen et al., 2007). Fixed-bed and fluidized-bed reactors are normally employed as gasifiers. However, due to the low reaction temperature, fixed-bed and fluidized-bed gasification have some disadvantages, including lower rates of biomass conversion, lower calorific value, and higher tar yield. Hence, entrained-flow gasification is a promising technology and is becoming increasingly important. This is primarily because entrained-flow gasifiers operate at high temperatures with small particles and can achieve a high carbon conversion rate with a low residence time. This feature in turn gives an entrained-flow gasifier a high capacity.Moreover, higher temperature impels the secondary-cracking of tar to reduce tar production. Much of the previous research has focused on coal gasification and on numerical simulations, leaving a need for a systematic study of biomass gasification in an entrained-flow gasifier. As research and development continues on entrained flow reactors, a mathematical model is necessary for gaining an insight into the influence of design variables, feed materials, and processing conditions on the reactor performance. Furthermore, such models will be necessary and powerful tools in optimizing, scaling-up and designing the process.The objective of this research is to develop a computer simulation model of a entrained fluidized bed biomassgasifier using Aspen Plus that can accurately predict gasifier performance under various operating conditions.

II. METHODOLOGY

2.1 Description of process:

Gasifiers are classified in terms of the movement of the fuel through the vessel, the operating pressure and temperature and the size and condition of the entering fuel. The primary configurations are moving/fixed bed, fluidized bed and entrained flow. In an entrained flow reactor, small condensed particles (solid or liquid state) are dispersed into a moving gaseous medium thereby entraining the injected particles. This provides the largest solid-gas (or liquid-gas) reactive surface area possible and reduces the gas phase diffusional resistances, so that rapid chemical reactions between the phases can occur.

2.2 Modeling of Biomass Gasifier

Aspen plus provides a unit operation model called RGIBBS that calculates chemical and thermodynamic equilibrium based on minimizing the Gibbs free energy of the system. Components in Aspen plus are classified as either conventional or nonconventional.Conventional components are ones with property data contained in the Aspen plus component database. Nonconventional components are non-homogeneous substances that do not have a consistent composition and are not contained in the Aspen plus component database. These components, which wouldinclude coal and biomass, must be given physical attributes, such as those defined by the ultimate,

proximate, and sulfur analyses. Property methods must also be chosen to calculate the enthalpy and density of the substance. For this work, the property methods HCOALGEN and DCOALIGT were respectively chosen to calculate the enthalpy and density of biomass. These property methods use statistical correlations to calculate the specific heat, enthalpy, and density of coal and coal-derived substances based on the ultimate, proximate, and sulfur analyses.Biomass can be represented as a technical fuel through these analyses, these property methods were also used for calculating the thermodynamic properties of biomass fuels. Furthermore, the property method HCOALGEN offers different options for how the enthalpy of formation of the component is calculated. For this work, the enthalpy of formation was calculated based on the higher heating value of the substance, which was specified through ultimate analysis ofbiomass.

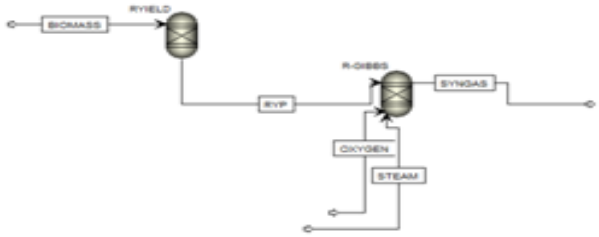

Figure1.Aspen flow sheet of entrained bed gasification

The equilibrium reactor RGIBBS does not accept nonconventional components as reactants. As a result, the fuel must be decomposed to conventional components which can be used by the RGIBBS block. The conversion is accomplished with an RYIELD block for the pyrolysis, labeled DECOMP, which isa reactor model that generates products based on known yields. The fuel feed stream enters DECOMP where it is decomposed into its elemental constituents. A FORTRAN calculator script interacts with the RYIELD block such that decomposition of the fuel is calculated based on the proximate and ultimate analyses of the nonconventionalcomponent. The carbon content of the feed is converted to solid carbon graphite. The hydrogen, oxygen, nitrogen, chlorine, and sulfur are converted to gaseous H2, O2, N2, Cl2, and S. Finally the moisture content is converted to liquid H2O. These species are now contained in an intermediate stream called RYP, which then become the reactants for the RGIBBS block. An O2/air and steam streams representing the gasifying oxidant also enters RGIBBS reactor, and a products stream exits it. The heat stream QRYP connect the RYP and RGIBBS reactor and represents the energy required to decompose the solid fuel. Although QRYP interactswith RGIBBS reactor, the reactor is still considered to be adiabatic because RYP calculates the amount of heat required for decomposition and draws it from RGIBS reactor.Gibbs model was used to predict the gasifier behaviour since many gasifiers produce near equilibrium products. The sensitivity analysis feature of Aspen Plus is used to study the effect of various combinations of H/C and O/C ratios. For specified H/C and O/C atomic ratios, the ultimate analysis in terms of mass percentage of the elements carbon, hydrogen, and oxygen is determined. In each case the total fuel flow rate is kept constant. For each case, a design specification of carbon entering equal to carbon leaving in gaseous species is used to determine the oxygen flow rate required for complete conversion of carbon. The main characteristics of the karanja oil cake are given in Table 1.

International Journal of Advance Research in Science and Engineering
Vol. No.5, Issue No. 04, April 2016
www.ijarse.com
IJARSE
ISSN 2319 - 8354

Table 1. Proximate and ultimate analyses

Feed stock	Proximate Analysis Composition				Ultimate Analysis Composition					
	FC	VM	Moisture	ASH	C	H	O	N	S	Cl
Karanja oil cake	17.48	70.00	08.12	04.40	56.71	05.30	33.70	04.29	-	-

III. RESULTS AND DISCUSSION

Sensitivity Analysis for Biomass Gasifier

The sensitivity analysis tool is used in this study to analyze and predict the behavior of the model to changes in key operating and design variables such as temperature, oxygen-to-biomass (ER), steam-to-biomass (S/B),Pressure on product gas composition by keeping fuel feeding rate constant inorder to determine the best working conditions of the biomass gasifier. During the sensitivity analyses the model input data was kept the same as for model validation with one parameter being varied at any given time.

3.1 Effect of Gasification Temperature on product gas composition

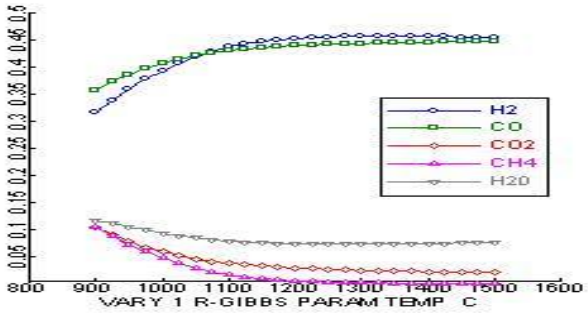

Figure 2. Effect of temperature on product gas composition

Since gasification is an endothermic reaction, the product gas composition is sensitive towards temperature change. Temperature is crucial for the overall biomass gasification process (Lv et al., 2004) and high temperature is a notable feature of entrained-flow gasification (usually 1300–1500 °C). It was observed that the concentration of H2 increases with increase in temperature. The concentration of CO remains almost constant over the range of temperature. Higher temperature provides more favorable condition for cracking and steam reforming of methane. So with increase in temperature the concentration of methane decreases in the product gas and this is attributed to increase in concentration of hydrogen. The CO2 concentration decreases with increase in temperature because higher temperature favors endothermic formation of CO from CO2 via boudouard reaction. In the present work, the oxygen/biomass ratio (Kg/Kg) was 0.225.Holding the other conditions constant, the reactor temperature was increased from 900 to 1500 °C in 25 °C increments. The test results are presented in Figs. 2 and 3. From Fig. 2, it can be seen that the H2 and CO contents increased remarkably with temperature, where CO2 and CH4 decreased. According to Le Chatelier's principle, higher temperatures favor the reactants in exothermic reactions and favor the products in endothermic reactions.

Therefore, increasing the temperature strengthened the endothermic reactions, such as reactions (1)–(3), resulting in increased H2 and CO contents and decreased CH4 and CO2 contents. Hence the H2 and CO concentrations reached maxima at 1227 °C. From Fig. 2, it can be inferred that higher temperature improved the H2 and CO yield. CO2 was produced from the decomposition of carboxyl groups (Huang et al., 2007) and reactions (4) and (5) at the low-temperature stage. However, higher temperatures were not favorable for the exothermic reactions (4) and (5), and the CO2 concentration therefore declined with increasing temperature, while the endothermic Boudouardreaction became more dominant, resulting in an increased CO content at the high-temperature stage. H2 and CO are the most important gas components of syngas, and determine the syngas quality. As shown in Fig. 2, the H2 and CO contents increased with the rise in gasifier temperature. As a result, cold gas efficiency also increased as the temperature increased from 900 to 1500 °C, as shown in Fig. 3.These results suggest that higher temperatures could improve syngas quality.

3.2. Effect of O/B

It is defined as the amount of O2 added relative to the amount of biomass added to the gasifier. The effect of equivalence ratio on product gas composition was studied in the range 0.2 to 0.5 at 1227°C with steam to biomass ratio 0.45.

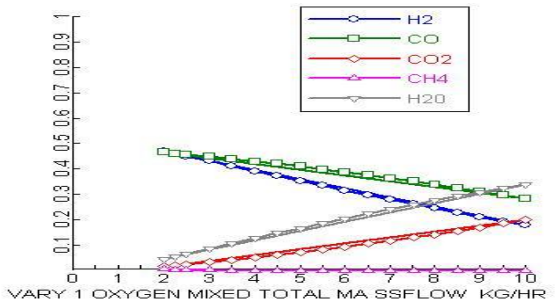

Figure 3.Effect of oxygen fow rate on product gas composition

The Figure3 shows CO2 concentration is directly proportional to the equivalence ratio. With increase in equivalence ratio more complete combustion of carbon takes place producing more CO2 and this leads to decrease in concentration of CO. So, less H2 is produced from water gas shift reaction which leads to decrease in concentration of H2. Methane concentration remains almost constant over the range of equivalence ratio. In a similar way H2O decreases reach minimum and then increases.With the introduction of O2, the CO concentration increased slowly and then decreased, CO2 increased sharply, H2 decreased rapidly, and the CH4 content was negligible. When the O2 content was low, H2 consumed part of the O2 to generate H2O. Carbon particles were incompletely combusted to generate CO, which resulted in CO content reaching a maximum of about 50%. When O2 was excessive, H2, CH4, CO and gaseous hydrocarbons from pyrolysis were completely combusted, which resulted in sharp increases in the CO2 concentration and continuous decreases in H2 and CO. As shown in Fig.3, as O/B increased, H2/CO declined. Hence, the introduction of excessive O2 did not improve the quality of the syngas. The carbon conversion efficiency increased with O/B and reaction temperature, as shown in Fig. 8, indicating that more carbon from the biomasswas burnt due to the influence of the O2, and higher temperature provided more energy for pyrolysis and gasification On the one hand, adequate O2 introduced into the reactor could strengthen the combustion to produce more heat to accelerate the gasification,

so improving the carbon conversion. Moreover the H2/CO ratio could be kept nearly constant at values of O/B between 0. 2 and 0.5. On the other hand, excessive O2 caused more CO2 to be produced, and increased the content of undesirable components. Considering the gas composition, H2/CO ratio, carbon conversion and LHV of syngas, 0.225 was found to be the optimal O/B value in this study.The influence of Tg on product gas composition is illustrated in Fig. 2. Tg depends on the oxygen flow, i.e. it is controlled by the ER. Therefore, varying ER or Tg will have the same effect on product gas composition, heating value, and CGE. The corresponding temperatures for ERs between 0.2 and 0.5 are given. In Fig. 2 H2,H2O, CO, CO2, and CH4 are plotted. The most interesting point from examination of Fig. 2 is that both H2 and CO reach a maximum at a temperature of 1227°C or at an ER of 0.225, after which their contents decrease steadily. H2O increases over the whole range but experiences a small decrease close to the H2 and CO peak. CO2 decreases rapidly up to a temperature of 1227°C and then increases slowly. CH4 decreases and eventually reaches zero between a temperature of 1227 and 1300°C (ER of 0.225 and 0.25).

3.3. Effect of Steam/Biomass Ratio

Steam to biomass ratio also plays an important role in gasification of biomass. The effect of steam to biomass ratio on product gas composition was studied over the range 0.2-1 at 1227 °C with equivalence ratio 0.225. Higher steam to biomass ratio favors more conversion of CO to CO2 and H2 through water gas shift reaction. So with increase in steam to biomass ratio H2 and CO2 concentration increases and CO concentration decreases in the product gas.

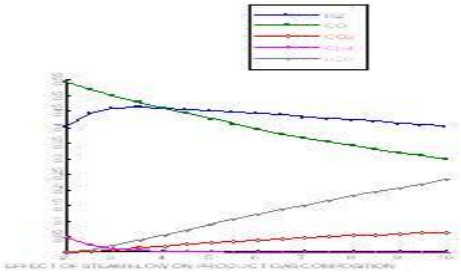

Figure 4.Effect of Steam flow on product gas composition

Also higher steam to biomass provides more favorable condition for steam reforming of methane. So methaneconcentration decreases with increase in steam to biomass ratio.

3.4. Gasification pressure

The effects of pressure variations on composition of syngas, its calorific value, and the gasification temperature are also investigated. While the pressure ranged from

atmospheric pressure 1 bar to 80bar, the equivalence ratio (0.225), gasification agent (pure oxygen), and air preheating temperature (25 C) were kept unchanged. Fig. 8 gives the syngas composition as a function of gasification pressure. It is observed that the amount of CO and H2 decrease slightly as the pressure increases. The CH4, CO2, and H2O contents, however, grow with increasing pressure. This trend, reported in the literature for other feedstocks can be explained in accordance with Le Chatelier's principle .Although increasing pressure reduces the rate of production of CO and H2, the syngas calorific value does not decrease due to the increasing

generation of CH4.the gasification temperature starts rising as the gasification pressure increases. This is because the endothermic behavior of the process dilutes with increasing pressure, which is expected as all the reactions responsible for conversion of char into gaseous product reverse at higher pressures in accordance with Le Chatelier's principle.

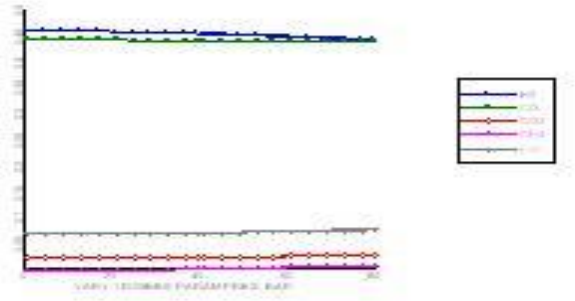

Figure 5.Effect of Pressure on product gas composition

A close inspection of the detailed results obtained from the simulations show that the gasification efficiency (both CCE and CGE) is not sensitive to the pressure changes.

The increase of CH4 concentration, which compensates the decrease of H2 and CO, results in such behavior. As observed, the gasification pressure has no significant effects on gasification characteristics. In reality, however, the gasification under pressure is economically preferred over pressurizing the syngas in downstream equipments such that all modern processes are operated at elevated pressures of at least 10 bar and up to a maximum 100 bar.

In this work 40 bar pressure found to be optimum.

IV. CONCLUSION

An entrained fluidized bed biomass gasifier model wasdeveloped using ASPEN Plus. The results obtained from the sensitivity analyses are in good agreement with published work. Therefore, the model is capable of predicting accurately gasifier performance over a wide range of operatingconditions.The influence of temperature, and level of air preheating on gas composition, oxygen to biomass ratio and steam to biomass ratio were investigated, the results of which revealed the following:

The optimal reaction temperature is considered to be 1227°C and the optimal equivalence ratio is 0.225.Higher temperature was beneficial to lower the amount of tar.The introduction of oxygen to the gasifier strengthened the gasification and improved the carbon conversion, but lowered the lower heating value and the H2/CO ratio of the syngas. The optimal steam /biomass ratio in this study was 0.45.

REFERENCES

[1] World Energy Technology Outlook - 2050.European Commission, 2006.

[2] J. Rezaiyan, and N.P. Cheremisinoff, "GasificationTechnologies", CRC Press, Newyork, 2001.

[3] A. Faaij, Modern biomass conversion technologies, Mitigation and Adaptation Strategies for Global Change 11 (2006) 335–367.

[4] Rezaiyan J., Cheremisinoff N. Gasification Technologies: A Primerfor Engineers and Scientists. FL: Taylor & Francis / CRC Press, 2005.

[5]. Li, X.; Grace, J. R.; Watkinson, A. P.; Lim, C. J.; Ergudenler, A. Equilibrium modeling of gasification: A free energy minimization approach and its application to a circulating fluidized bed coal gasifier. Fuel 2001, 80, 195–207.

[6]. Paviet, Chazarency, &Tazeroutz,Thermo chemical equilibrium modelling of a biomass gasifying processusng ASPEN PLUS. International Journal of chemical reactor engineering, (2009),7(1), 1542-6580.