Simulation of Biomass Gasification in Downdraft Gasifier using Aspen Plus

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***Abstract*—The purpose of this study is to study the simulation of biomass gasification in downdraft gasifier using ASPEN Plus and to identify the characteristics and chemical composition of biomass. To achieve this objective, the chemical and physical characteristics of biomass and how to simulate the biomass gasification process in downdraft gasifier using Aspen Plus were studied. Simulation of biomass gasification was done using Aspen Plus. The parameter that were used to study the simulation of biomass gasification using Aspen Plus were the effect of gasification temperature and air-fuel ratio towards the amount of syngas produced. It was observed that the gasification product which is syngas was dependent on the gasification temperature and the air-fuel ratio used.**

***Keywords*— Aspen Plus, biomass gasification, downdraft gasifier, simulation.**

I. INTRODUCTION

Gasification is considered as the most suitable option for energy production from biomass. It is because the technology is a simple and economically viable process to produce thermal energy or decentralized electricity generation. Downdraft gasifiers are typically small-scale units having maximum power production capacity up to 5 MW. This make it more suitable for decentralized power generation and distribution to the remote villages that does not have grid electricity. However, in Malaysia, gasification technology is still under developing stage and most of the on-going research is in the laboratory scale. In order to commercialize the technology, it needs to scale up. In order to scale up the biomass gasification technology, the simulation using ASPEN plus software is necessary. Simulations provide a less expensive ways to evaluate the benefits and risks of gasification. So, simulation of gasification provides a better understanding of physical and chemical mechanisms inside the gasifier and help in optimizing the yield. However, based on Malaysian biomass the study is not adequately conducted. This study focussed on simulating the existing downdraft gasification technology in order to scale up for commercial use.

In Malaysia, gasification is rarely used in large scale in industry because of lack of knowledge on the gasification process and lack of data to scale-up and optimize the process. In addition, in order to simulate the process in Aspen Plus, we need to specify the amount of feed that we use in the reaction. For biomass, different biomass has different characteristics and chemical composition. So, we need to identify the characteristics and chemical composition of the biomass before we do the simulation.

II. METHODOLOGY

A. *Simulation assumptions*

The following assumptions are employed to simplify the simulations of biomass gasification (Po-Chih Kuo, Wei Wua, and Wei-Hsin Chen, 2014):

1) Biomass gasification processes are isothermal and in steady state.
2) The gasifier is operated at the thermodynamic equilibrium state; that is, the residence time of reactants is sufficiently long so that the reactions in the reactor are in chemical equilibrium.
3) The feedstock is at normal conditions (i.e. 25 °C and 1 atm).
4) The product gas is a mixture of H_2O, N_2, H_2, CO, CO_2, and CH_4, and all the gases follow the ideal gas law.
5) The sulphur content in the feedstocks and the formation of air pollutants, such as COS, H_2S, CS_2, NH_3, and HCN, are neglected.
6) Char contains solid carbon (C) and ash alone, and tar formation is disregarded.

B. *Gasification Models*

Feed is specified as a non-conventional component in Aspen Plus and defined in the simulation model by using the ultimate and proximate analysis. The model is based on minimization of the Gibbs free energy at equilibrium. This simulation is developed under the assumption that the residence time is long enough to allow the chemical reactions to reach an equilibrium state. The characteristic of biomass (empty fruit bunch, EFB), input parameters of gasifier operating conditions and gas composition from experimental data are given in Table 1, Table 2, and Table 3 respectively.

Proximate analysis	**(wt %)**
Moisture content	7.80
Volatile matter	79.34
Ash content	4.50
Fixed carbon	8.36
Ultimate analysis	**(wt %)**
Carbon	43.52
Hydrogen	5.72
Oxygen	48.90
Nitrogen	1.20
Sulphur	0.66

Table 1: Characteristics of biomass

Items	**Parameters**
Ambient conditions	25 °C and 1 atm
Input conditions	Fuel: 25 °C and 1 atm
	Air: 25 °C and 1 atm
Gasifier	900 °C

Table 2: Input parameters of gasifier operating conditions

Gas Composition	Percentage (%)
H_2	10.94
N_2	32.15
CO	17.44
CH_4	2.32
CO_2	16.18
Total	79.02

Table 3: Gas composition from experimental data

C. *Property Method*

In this study, Peng Robinson equation of state has been used to estimate all physical properties of the conventional components in the gasification process (Po-Chih Kuo, Wei Wua, and Wei-Hsin Chen, 2014). The enthalpy and density model selected for both feed and ash are non-conventional components, HCOALGEN and DCOALIGT. In this study, feed was defined as non-conventional components from the perspectives of ultimate and proximate analysis (Table 1). Ashes were also defined as a non-conventional component with an ash content set to 100% (Sharmina Begum, M. G. Rasul, and Delwar Akbar, 2014).

D. *System Description*

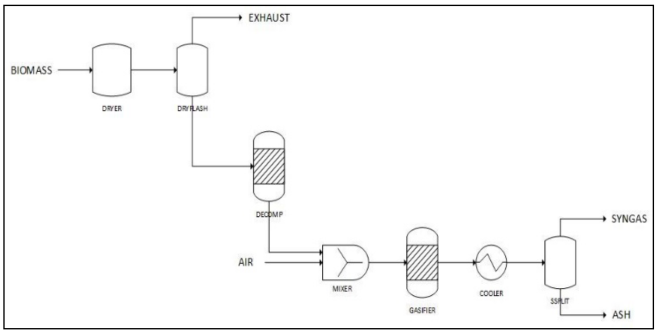

Figure 1: Process flow diagram of the biomass gasification process

For the purpose of analysis, the reaction zones are represented by a number of blocks. Fig. 1 shows the flow chart of biomass gasification process and Table 4 gives the brief descriptions of the unit operations of the blocks. The stream BIOMASS was specified as a nonconventional stream and it was defined in terms of proximate and elemental analyses. When BIOMASS was fed into the system, the first step was the heating and drying of biomass. The blocks DRYER and DRYFLASH were used to model the drying process, and the moisture in the feedstock was removed from EXHAUST stream, as shown in Fig. 1. After drying, the devolatilization stage was performed in the block DECOMP in which the RYield reactor was used. In DECOMP, the feedstock was transformed from a non-conventional solid into volatiles and char. The volatiles consisted of carbon, hydrogen, oxygen, and nitrogen, and the char was converted into ash and carbon, based on the ultimate analysis. The yield of volatiles was equal to the volatile content in the fuel according to the proximate analysis.

Moreover, the actual yield distributions in DECOMP were calculated by a calculator block which was controlled by FORTRAN statement in accordance with the component characteristics of the feedstock. The combustion and gasification of biomass were simulated by a block called GASIFIER in which the chemical equilibrium was determined by minimizing the Gibbs free energy. The product stream was then cooled to room temperature by COOLER. AIR was used as oxidizing agent. Eventually, the product gas was divided into two streams SYNGAS and ASH in the block SSPLIT.

Block name	**Aspen Plus name**	**Function**
DRYER	RStoic	Drying of fuel
DRYFLASH	Flash2	Calculation of vapour-liquid equilibrium
DECOMP	RYield	Decomposition of fuel according to its proximate and ultimate analysis
GASIFIER	RGibbs	Gasification and combustion of fuel
COOLER	Cooler	Cooling of product gas
SSPLIT	SSplit	Separation of inert ash from product gas
MIXER	Mixer	Mix AIR and outlet from DECOMP

Table 4: Descriptions of unit operations

III. RESULTS AND DISCUSSION

A. Sensitivity Analysis: Gasification Temperature

Gasification temperature in the simulation was varied from 900°C - 1100°C. The effects of gasification temperature towards syngas composition were studied. The variation in syngas composition with gasification temperature can be understood by considering that rising temperature favours the products of endothermic gasification reactions and simultaneously the reactants of exothermic reactions. From these, it can be concluded that gasification temperature is one of the the most important parameter with respect to syngas composition.

B. Sensitivity Analysis: Air-fuel ratio

Air-fuel ratio plays an important role in the performance of biomass gasification. A low air-fuel ratio will lead to biomass reactions approaching pyrolysis, whereas a high air-fuel ratio causes biomass combustion. From the simulation, it shows that the concentration of H_2 decreases with increasing air-fuel ratio. Similar to H_2 formation, the CO concentration also decreases with increasing air-fuel ratio but an opposite trend in CO_2 concentration is exhibited. This can be explained by more oxygen supplied for biomass reactions which have a trend toward fuel combustion when air-fuel ratio rises.

IV. CONCLUSION

In conclusion, in Malaysia, gasification technology is still under developing stage and most of the on-going research is in the laboratory scale. In order to commercialize the technology, it needs to scale up. In order to scale up the biomass gasification technology, the simulation using ASPEN plus software is necessary because simulation of biomass gasification using Aspen Plus provide a less expensive means to evaluate the benefits and risks of gasification. So, simulation of gasification provides a better understanding of physical and chemical mechanisms inside the gasifier and help in optimizing the yield.

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