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ASPEN PLUS SIMULATION OF BIOMASS GASIFICATION FOR DIFFERENT TYPES OF BIOMASS: EMPTY FRUIT BUNCH, SAGOO HUSK AND ACCACIA

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Abstract

Much attention has been focused on reducing the use of petroleum products as fuels, so synthetic gas (Syngas) provides a great opportunity for sustainable energy development. Syngas is made through gasification of plant biomass or pyrolysis of (carbon-based) waste products. In principle, Syngas can be produced from any hydrocarbon feedstock. This study generally reviews the comparison of syngas yield (H_2, CO_2, CO, CH_4) and electricity potential from three different types of biomass, namely from oil palm empty fruit bunches.

Keywords: Aspen Plus, Simulation, Biomass, Syngas, Comparison.

Abstrak

Banyak perhatian telah terfokus pada pengurangan penggunaan produk minyak bumi sebagai bahan bakar, sehingga gas sintetis (Syngas) memberikan peluang besar bagi pembangunan energi berkelanjutan. Syngas dibuat melalui gasifikasi biomassa tanaman atau pirolisis produk limbah (berbasis karbon). Pada prinsipnya, Syngas dapat diproduksi dari bahan baku hidrokarbon apa pun. Penelitian ini secara umum mengulas perbandingan Yield syngas (H_2, CO_2, CO, CH_4) dan potensi listrik dari ketiga jenis biomassa yang berbeda yaitu dari tandan kosong kelapa sawit.

Kata Kunci: *Aspen Plus, Simulasi, Biomassa, Syngas, Perbandingan.*

A. INRODUCTION

Due to increasing energy demand, and rising global temperatures, research is focused towards alternative energy sources such as wind energy, solar energy, and solar energy and energy from biomass. Biomass sources such as sawdust, coconut shells, food waste, wood waste, rice husks, bagasse and waste poultry manure can be utilized to produce product gases (CO, H2 and CH4) through biomass gasification. Biomass gasification is the thermochemical process of converting carbonaceous materials, primarily into syngas (a mixture of CO and H2), with the application of gasification media such as air, steam, and oxygen. Syngas can be converted into liquid fuels through Fischer-Tropsch (FT) synthesis, also known as Gas-To-Liquid (GTL) process [1] .

Modeling and simulation of biomass gasification is an emerging field of research. Aspen gasifier models can be useful for design, analysis of gasifier behavior and prediction of operational conditions during start up and shut down, that experiments are usually expensive and inappropriate, when performed at larger scales [2–4]. However, modeling can save time and cost and also has the ability for optimization in real time [5]. Biomass-based conversion processes have been simulated by many researchers with the help of Aspen Plus [[6–25]. The reaction kinetics used in the gasification process as shown in table 1.

Table 1 – Gasification reaction scheme [26,27]

Proses	*ΔH (kJ/mol)*	
Drying Wet Biomass + Heat → Dry Biomass + H_2O	-	R1
Pyrolisis Dry Biomass → char + tar + Syngas + ($CO+CO_2+H_2+CH_4+N_2+C_xH$	+131.5	R2
Oxidation		
$C+\frac{1}{2}O_2 \rightarrow CO$	-111	R3
$C+O_2 \rightarrow CO_2$	-394	R4
Reduction		
$C+CO_2 \rightarrow 2CO$	+173	R5
$C+H_2O \rightarrow CO+H_2$	+131	R6
$CO+H_2O \rightarrow CO+H_2$	-42	R7
$C+2H_2 \rightarrow CH_4$	-75	R8
$CO+3H_2 \rightarrow CH_4+H_2O$	-206	R9

B. LITERATUR REVIEW

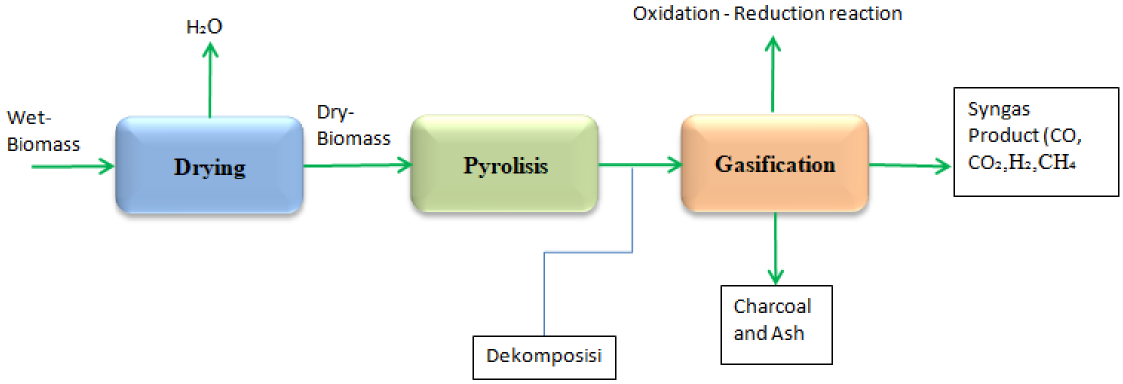
Nikoo and Mahinpey simulated biomass gasification in a fluidized bed reactor. The model was validated with experimental results from a laboratory-scale fluidized bed reactor. The effect of different parameters such as temperature, equivalence ratio, STBR and biomass particle size was studied during their simulation [28].

Liu et al. studied biomass gasification simulation based on Gibbs equilibrium. model

The validated model was used to study the effects of gasification temperature, pressure and equivalence ratio. The optimal equivalence ratio was about 0.3 with an optimal gasification efficiency of 85.92% [29].

Sharma simulated to increase the hydrogen content of producer gas, steam is used along with air in a gasifier. In this study, extensive experimental work was carried out in a downdraft gasifier using both air and steam and is referred to as steam-air gasification. After reaching steady state conditions with air gasification, saturated steam was injected into the reduction zone of the gasifier and its effect on the performance of the gasifier was evaluated [30].

Gagliano et al. have developed a model-based equilibrium model in Aspen Plus to predict the chemical composition of product gas for different types of biomass with different moisture contents. There is a good agreement of gas composition between simulation results and experimental results for pellets and rubberwood [31].



Pict 1 - Biomass gasification flow chart

The purpose of this paper is to compare the syngas potential between the biomass of oil palm empty fruit bunches, sago and acacia.

C. MATERIAL AND METHODE

1. Material

Ultimate main analysis and proximate analysis on dry basis of EFB [32], Sago [33] and Acacia [34] can be seen in Table 2.

Table 2 – Chemical composition

	Proximate Analisis (%)				*Ultimate Analisis (%)*					
	Moisture	**FC**	**VM**	**Ash**	**C**	**H**	**O**	**N**	**S**	**CL**
EFB	7.8	8.36	79.34	4.5	43.52	5.72	45.06	1.2	0	0
Sago	10.3	16.3	71.1	2.3	44.147	6.09	47.46	0.001	0.001	0.001
Accasia	3.79	19.21	72.99	4.01	41.47	5.15	48.14	1.23	0	0

2. Model Process

A steady-state equilibrium model has been developed for the gasification process using Aspen plus.

1) Assumptions

The assumptions considered in this simulation process are as follows:

- The process is carried out under steady state conditions and atmospheric pressure.
- The devolatization process produces synthetic gases H_2, CO, CO_2, CH_4 and O_2.
- The reaction takes place under isothermal and constant volume conditions.
- Heat and pressure losses are negligible.
- Constant temperature in the gasifier and perfect mixing.

2) Thermodynamic Properties Package

In Aspen plus, there are several options for property methods and equation of state methods [35]. In this study, the Peng-Robinson equation was used to estimate all physical properties of conventional components in a steady-state simulation in Aspen plus. The Peng-Robinson equation itself is considered suitable for the gasification process because it improves the vapor pressure correlation of pure components [21].

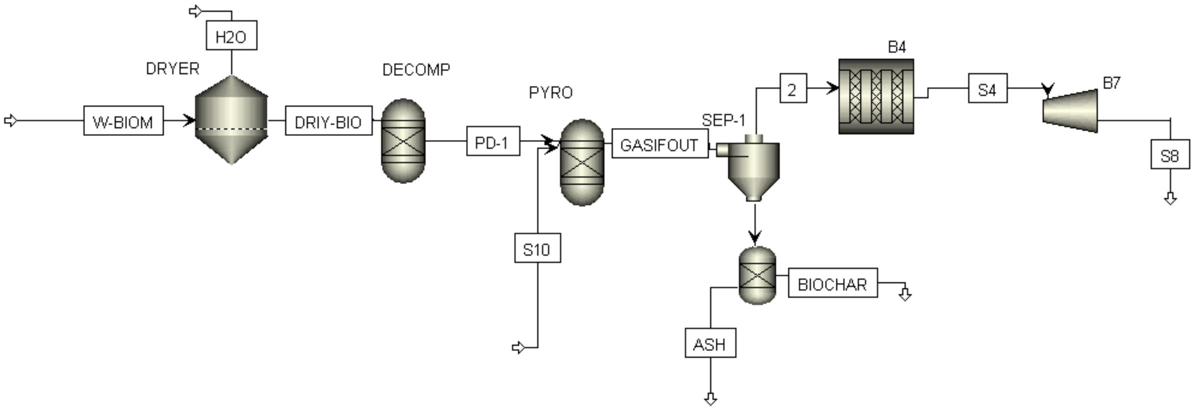
3) Simulation Process

To simulate the gasification process, an equilibrium model was developed using Aspen plus V.14 software. The flowchart of the biomass gasification system developed in Aspen plus software is illustrated in figure 2. The gasification process consists of three interrelated processes: drying, pyrolysis and biomass gasification. The list of components used in the simulation model is shown in table 2. Biomass is designated as a non-conventional component in the Aspen plus tool and is defined using ultimate and proximate analysis.

Table 3 - List of compounds used in the simulation

Componen ID	*Type*	*Name of Componen*
Biomassa	Non-Konvensional	-
Ash	Non-Konvensional	-
C	Solid	Carbon
H_2O	Konvensional	Water
S	Konvensional	Sulpur
CO	Konvensional	Karbon-monoksida
CO_2	Konvensional	Karbon-dioksida
N_2	Konvensional	Nitrogen
CL_2	Konvensional	Chlorine
H_2	Konvensional	Hidrogen
O_2	Konvensional	Oksigen
CH_4	Konvensional	Methane

The HCOALGEN and DCOALIGT models have been used to calculate the enthalpy and density of biomass and ash considered as non-reactive and non-conventional solids. The drying process is carried out in a dryer. The dried biomass is then heated by RGibbs as a step to pyrolyze the dried biomass into its constituent components and main products such as H_2, H_2O, C, O_2, N_2, S and Ash. Then the oxidation, reduction stages are carried out in the Rplug reactor



Pict 2 - Aspen plus gasification simulation flow

Tabel 4 - Aspen Plus unit Operation and material model

	Aspen Plus Blok	*Blok (Stream) ID*	*Deskripsi*
Stream	Material	Biomassa basah	Wet biomass input (Mass flow rate 1000 kg/h; Temp 25˚ Pressure 1 atm)
	Material	Steam (H_2O)	Nitrogen gas enters as an agent
	Material	Biomassa kering	Dry biomass before Pyrolysis
	Material	Gasifout	Gasified gas mixture
	Material	Air	Inlet air (flow 100 kg/h)
	Material	Ash	Ash as residue
	Material	Charcoal	Solid carbon (Char) from gasification residue
	Material	Syngas	Synthetic gas as a product
Blok	Dried	Drying	Removing moisture elements
	Ryield	Dekomp	Separation of biomass into specific components such a H_2, H_2O, CO, CO_2, N_2, S and Ash
	RGibbs	Pyrolisis	Gibbs free energy reactor limiting prescribed chemica equilibrium (1-20 atm) and temperature (500-1200˚C)

Split	SEP1	Separation of gaseous elements from solid (syngas fror char)
Rplug	Oksidasi-Reduksi	Chemical reactions of oxidation and reduction
Turbin	Engine	Gas engine for electricity production from gas

The process consists of several stages such as biomass decomposition (DECOMP), pyrolysis (PYRO), gasification (GASIFIER), combustion (COMB) and different separation units (cyclones and separators). The MIXNCPSD flow class is used as the conventional flow class Figure 2 shows the flow sheet in Aspen Plus. Biomass is decomposed into its constituent elements such as H_2O, ash, C, H, N, Cl, S, O based on analysis.

The decomposed biomass product enters the yield reactor, simulating the pyrolysis step in gasification. The PYRO reactor is set to operate at 800°C. The products of pyrolysis are separated using a cyclone. The char produced after pyrolysis is taken to another yield reactor (GASIFIER), which is simulated as a gasification reactor.

About 5% of the charcoal is burned in the RStoic reactor. The resulting energy can be used as additional heat for the gasifier. In addition to the char, gaseous products (nitrogen-free) from the pyrolysis process and steam are added to the gasifier. The calculations in the RGibbs gasifier are based on finite equilibrium with a zero approximation temperature for each reaction. The zero approximation in RGibbs calculates a constant chemical equilibrium for the specified reaction at the reactor operating temperature. The equilibrium state of the reactor also depends on the load per reactor area. Low loads give a near-equilibrium state whereas higher loads give a non-equilibrium state in the reactor. High loads are preferred to achieve a high conversion rate and low equipment costs. An overview of the temperature and pressure inside different reactors is presented in Table 2.

	Termodinamik	
Reactor	**Temperatur (˚C)**	**Pressure(atm)**
Drying	100	1
Decomposition	250	1
Pyrolisis	800	1
Gasifier	800	1

D. RESULT AND DISCUSSION

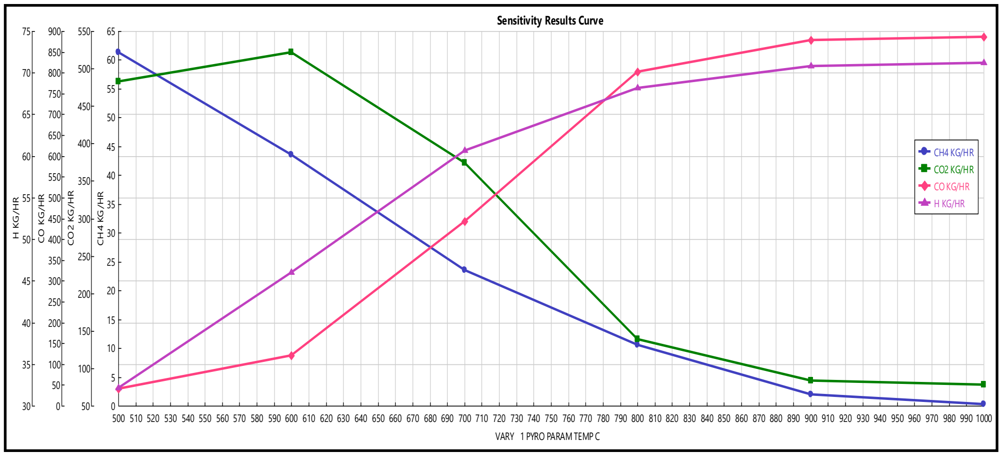
The simulation model was developed and evaluated by varying the synthetic gas composition with temperature, pressure and vapor to biomass ratio in Aspen plus.

1. Effect of Gasification Temperature on Syngas compositions

The effect of gasifier temperature on syngas from biomass and steam as interconnected gasifiers has been analyzed and reported. The temperature was varied from 500-1000˚C. at a constant pressure of 1 atm, with a steam to biomass ratio of 0.5. Then the composition of the Syngas product as a function of gasifier temperature is shown, as shown in Fig.3.

The results show that temperature has an effect on syngas yield. The production of H_2 and CO_2 increases as the temperature increases. In contrast, the composition of CH_4 and CO_2 decreased. The hydrogen value increases and then remains constant at 800˚C, a series of reactions occur in biomass gasification, resulting in the production of syngas. Endothermic processes occur in the first two reactions while the water gas shift reaction (8) is an exothermic reaction. Consequently, higher temperatures will result in reactants in exothermic reactions and products in endothermic reactions.

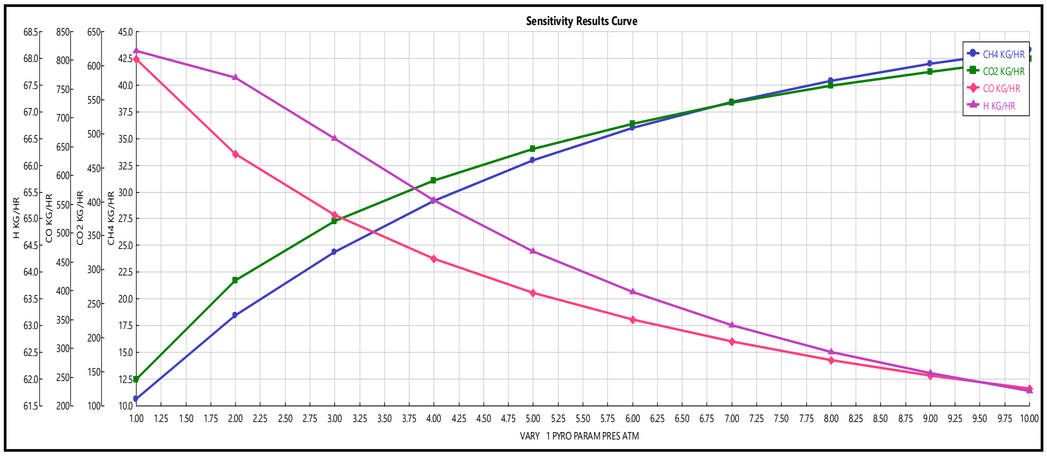
It is clear that the hydrogen yield is higher than CO and there is a difference in yield due to the reaction activity of water gas, CO and H_2 composition changes in the range of 500 - 1000˚C. The effect of gasifier temperature on H_2 yield as shown in Fig. 4 shows that the hydrogen yield increases with increasing gasifier temperature. The favorable operating temperature range is 800-1000˚C corresponding to higher hydrogen yield.



Pict 5 – Temperature sensitivity graph (˚C) – Mass flow (Kg/Jam)

2. Effect of Gasification Pressure on Syngas composition

Gasifier pressure is another important operating parameter that has a great impact on the performance of the gasification process. Higher operating pressure performance may be favorable for gasification due to faster reactions. In addition, higher pressures improve process efficiency in terms of energy and exergy, as downstream processes usually involve pressurized gas flow. Le Chatelier's principle implies that an increase in pressure moves the equilibrium conditions to the side of the reaction with fewer moles of gas, while a reduction in pressure moves the equilibrium to the side of the reaction with a larger number of moles of gas. gasifier pressure in the range of 1-10 atm at dry and free air syngas mole fractions for biomass in Figure 5. Thus, due to the kinetics of the main reactions of the gasification process (Table 1), increasing the gasifier pressure results in the production of carbon dioxide and char (carbon) through Bouduard (R-6) and vapor-carbon (R-7) reactions. In addition, hydrogasification (R-8) and methanation (R-9) reactions lead to methane production. Figure 6 illustrates the effect of gasifier pressure on H_2 production yield. As shown in this figure, hydrogen yield decreases with increasing gasifier pressure and at 1 atm pressure, all feeds have maximum hydrogen production [36].

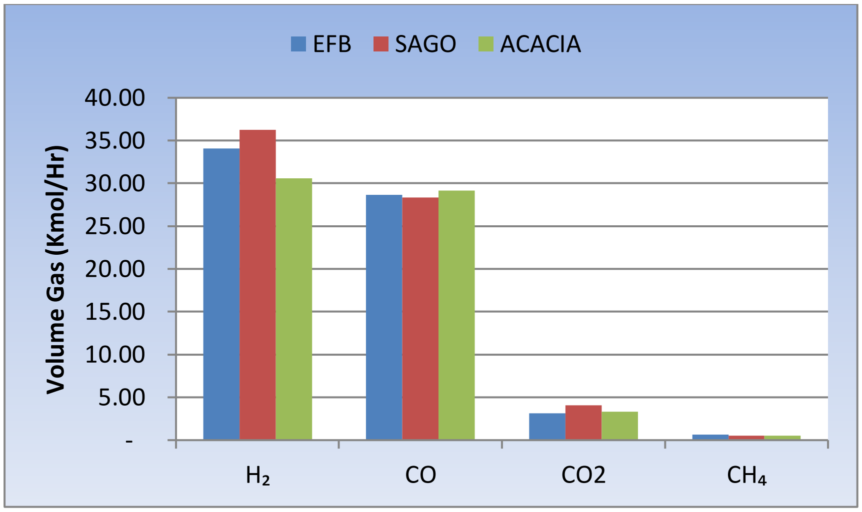


Pict 6 – Pressure sensitivity graph (atm) – Mass flow (kg/jam)

3. mulated Gas Products

Based on the results of the Aspen plus simulation, the total production of syngas composition, shown in table 5 The results of data processing based on stream condition parameters and certain blocks according to simulation conditions as shown in Figure 2.

Table 5 - Syngas yield from different biomasses



In this study, the highest hydrogen concentration was 36.25 kmol / hour at a gasification temperature of 800 ° C in sago biomass while the highest CO in acacia biomass was 29.14 kmol / hour and the highest methane gas in EFB biomass was 0.66 kmol / hour, while the electrical potential of EFB, sago and acacia biomass obtained results with 15.67 kWe, 16 kWe and 15 kWe respectively.

E. CONCLUSIONS

A simulation model was developed for biomass gasification in an atmospheric gasifier using the aspen plus V.14 simulator. Sensitivity analysis was performed to evaluate the gasifier performance as a function of gasifier temperature and steam to biomass ratio. Simulation results for product gas composition as a function of temperature and pressure to biomass are reported. Higher temperatures improve the gasification process as well as the product gas yield. Increasing temperature shows that hydrogen and CO contents increase with the most optimal product gas achieved at gasifier temperatures of 800-900°C.

Furthermore, this simulation model is sufficient to predict the performance of the gasifier over a range of operating conditions. The model is also suitable for simulating other feedstocks such as wood, green waste, bagasse, etc. Therefore, this model can be fully utilized to support the design of experimental campaigns.

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