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Simulation of Hydrogen Gas Production Process from Oil Palm Empty Fruit Bunch (OPEFB) Combine with Carbon Capture Based on Aspen Plus Software

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Abstract. This research discusses the biomass gasification process for hydrogen production, integrated with a carbon capture process for product purification. A new simulation model was developed in Aspen Plus, incorporating a gasifier, a water–gas shift (WGS) reactor, and a carbon capture unit. Oil palm empty fruit bunches were selected as the biomass feedstock. The simulation investigated the effects of different gasification agents (O_2, air, and steam) and gasifier operating temperatures on hydrogen yield. It also evaluated the influence of MDEA solvent flow rate on CO_2 capture efficiency. Results showed that using a mixture of O_2 and steam with a ratio of 0.5 at 800 °C produced favorable outcomes, with negligible impurities. The addition of steam in the WGS reactor enhanced hydrogen production, with the highest yield achieved at a steam ratio of 0.6. A 2:1 molar ratio of MDEA to CO_2 resulted in up to 99.9% carbon dioxide removal.

Introduction

Indonesia is one of the largest archipelagic countries in the world and has a lot of natural beauty. Indonesia is also blessed with rich natural resources such as petroleum, natural gas, coal, and many others. Until now, almost 90% of energy sources in Indonesia still come from fossil energy. Unfortunately, energy sources derived from fossils are non-renewable energy sources, or it can be said that these energy sources will become depleted in the future. One energy source that is considered important is hydrogen because hydrogen is expected to replace hydrocarbon-based fuels which are currently running low. Hydrogen is projected to be one of the alternative energy sources that can be sustainable.

Hydrogen gas can be produced through synthesis gas (syngas) sources, since syngas is primarily composed of CO and H_2. Syngas can be obtained from several sources such as biomass, coal, and natural gas. Biomass is one of the options to be a renewable energy source. Biomass, which is an organic waste, is expected to be a renewable energy source because biomass will continue to be produced. The use of biomass as a source of hydrogen production is the best choice, this can be done by the biomass gasification process.[1]

Before the recognition of fossil fuels, humans first utilized biomass as an energy source. Biomass is organic material derived from living organisms such as plants and animals and their by-products, either alive or dead. Biomass can be produced from plants, trees, agricultural waste, forest waste, and human and animal waste. Biomass can also be utilized for many things such as animal feed, building materials, vegetable oil, food sources, and even energy sources. In general, biomass used as an energy source (fuel) is material that has economic value such as waste from a product. Indonesia is one of the countries with the potential to utilize biomass as an energy source because it has an abundant source. Indonesia has a biomass potential of 146.7 million tons per year.

Several methods can be used to process biomass into syngas, namely thermochemical, biochemical, and mechanical extraction. The thermochemical process is a technique used to convert

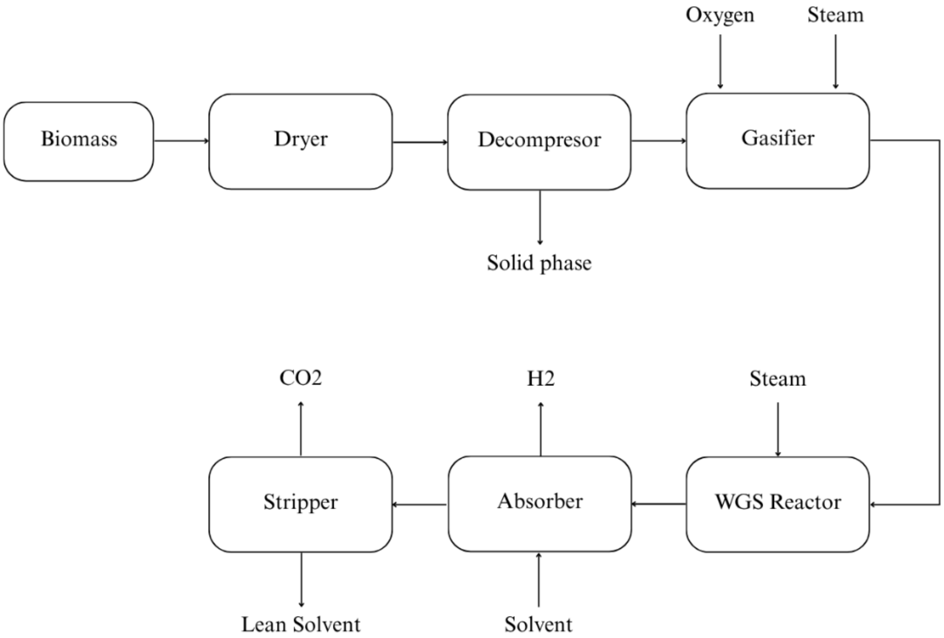

Fig. 1 Structure of the biomass Gasification-Hydrogen Production Process

biomass into syngas by utilizing thermal or heat. This thermochemical process can convert biomass into gases such as H_2, CH_4, CO, CO_2, and H_2S, with conversion results influenced by the volatile matter composition of each biomass. So in general, to increase hydrogen gas production from biomass through gasification, this process will be combined with water gas shift (WGS) to increase hydrogen gas production.[2]

Thermochemical extraction methods can be divided into pyrolysis, combustion, liquefaction, and gasification. One of the most commonly used commercial methods of producing syngas from biomass is gasification. Gasification of biomass is also considered advantageous as it provides a renewable source of energy and is considered to be more environmentally friendly.[3]

Biomass gasification is an attractive technology for converting various types of biological waste into energy. Gasification has also become a clean and efficient way to produce hydrogen, because it has several advantages, namely a fast, efficient, environmentally friendly process, as well as a renewable energy source Safarian et al [3]. In general, the biomass gasification process can be classified into three steps: drying, decomposition, and gasification reaction. First of all, the feedstock will be dried by heating, then the dried biomass will be further degraded or pyrolyzed. Products resulting from the decomposition process in the form of gases and solids will then react with each other and with the gasification agent used to form the desired final product. The gasification process works in the presence of gasification agents, these gasification agents will react with solid carbon and hydrocarbons to convert these compounds into lower molecular weight gases such as CO and H_2. There are several gasification agents, namely oxygen, air, steam, or a mixture of the two.[4]

To increase hydrogen gas production from biomass gasification syngas, the addition of a water gas shift (WGS) unit is required. The water gas shift reaction is a reaction used since ancient times to produce hydrogen gas from synthesis gas (syngas). Initially, the WGS reaction was used in the fertilizer industry to produce ammonia, and petroleum refineries for various operations. Currently, the WGS reaction is also used in gasification processes aimed at electricity production, as well as hydrogen production as a fuel. In producing hydrogen gas from fossil fuels, biomass, or syngas, the water gas shift reaction is an important procedure for converting water to hydrogen and oxidizing carbon monoxide to carbon dioxideMDEA is one.[5]

Although considered environmentally friendly, the synthesis gas produced from the biomass gasification process contains CO_2 gas, which has been a major contributor to greenhouse effect gas pollution. Although the CO_2 gas produced from biomass is considered neutral, reducing CO_2 gas emissions must still be done to reduce greenhouse effect pollution. One of the ways that can be done to minimize CO_2 gas emissions is by absorbing CO_2 in the absorption column, this process is a common process carried out in the gas processing process to reduce the resulting CO_2 emissions.[1]

Amine solution is one of the best choices to be used as carbon capture media. MDEA is one of the best choices for an amine-based carbon capture solution today. This solution has many advantages such as not requiring high heat to react, not being so corrosive, being used at high concentrations, and being easy to regenerate. The amine-based carbon capture process has two main processes: capture and release. The process of carbon capture or absorption in the amine solution is carried out in the absorber reactor. While the release or regeneration process is carried out in the stripper reactor.[6]

Therefore, the purpose of this research is to develop a new simulation model using Aspen Plus for the hydrogen gas production process by gasification integrated with the carbon capture process from oil palm empty fruit bunches (OPEFB). In addition, sensitivity analysis was conducted to study the effect of gasification agent ratio and gasification temperature on syngas composition, H_2/CO ratio, and efficiency. Analysis was also carried out on the WGS reactor by studying the effect of adding steam on the hydrogen gas and carbon dioxide produced. The analysis of the carbon capture process was carried out by studying the effect of solvent ratio on carbon dioxide that can be absorbed. Thus, this research can provide a framework for hydrogen gas production plants that use the gasification process. This research is expected to be used as a reference material and consideration before building the actual process in the field.

Table 1 Ultimate and Proximate Analysis of Biomass

Analysis	Content	%
Proximate	Moisture	2.75
	Volatile Matter	76.09
	Fixed Carbon	18.15
	Ash	5.8
Ultimate	C	66.17
	H	9.54
	N	1.51
	S	0.06
	O	22.72

Material and Methods

System Description. The system that will be used in this study is shown in Figure 1. Oil Palm Empty Fruit Bunches (OPEFB) are used as the biomass feedstock. The characteristics of the PKS are shown in Table 1. In the drying process, the moisture content of the PKS will be removed. In the decomposition stage, the biomass will be heated under conditions of very little oxygen or air supply, under these conditions the volatile content of the biomass will evaporate separately from the solid phase of the biomass. The released gas will enter the gasifier react with oxygen and steam as a gasification agent, and form H_2, CO, CO_2, CH_4, and H_2O gases. In this process, oxidation, reduction, and cracking will occur. The reactions that occur in the gasification process are shown in Table 2.

Table 2 Main Gasification Reactions

Reaction	ΔH	
$\mathbf{H_2O\ (l) \rightarrow H_2O\ (g)}$	-40.7	Drying
$\mathbf{Biomass \rightarrow Char + VM}$	-	Decomposition
$\mathbf{C + O_2 \rightarrow CO_2}$	394	Complete Combustion
$\mathbf{C + \frac{1}{2}O_2 \rightarrow CO}$	111	Partial Combustion
$\mathbf{C\ +\ CO_2 \rightarrow 2CO}$	-172	Bououard
$\mathbf{C + H_2O \rightarrow CO + H_2}$	-131	Water Gas
$\mathbf{C + 2H_2 \rightarrow CH_4}$	75	Methanation
$\mathbf{CO + \frac{1}{2}O_2 \rightarrow CO_2}$	283	CO Partial Combustion
$\mathbf{H_2 + \frac{1}{2}O_2 \rightarrow H_2O}$	242	H_2 Combustion
$\mathbf{CH_4 + H_2O \rightarrow CO + 3H_2}$	206	Reforming
$\mathbf{H_2 + S\ \rightarrow H_2S}$	20,2	H_2S Formation
$\mathbf{3H_2 + N_2 \rightarrow 2NH_3}$	92	NH_3 Formation
$\mathbf{CO + H_2O \rightarrow CO_2 + H_2}$	42	Water Gas Shift

After going through the gasification process, the syngas product will enter the water gas shift reactor with the reaction:

$$CO + H_2O \leftrightarrow CO_2 + H_2 \tag{1}$$

This process consists of two reactors, namely High-Temperature Water Gas Shift (HT-WGS) and Low-Temperature Water Gas Shift (LT-WGS). The output syngas product from WGS is dominated by hydrogen and carbon dioxide, there is also residual steam, CO, and unreacted CH4.

To purify the hydrogen gas, the syngas product will then be put into the absorber for the carbon capture process. The absorption process is carried out by bringing together syngas with MDEA solvent, and then pure hydrogen gas will be obtained. MDEA solvent containing carbon dioxide and other gases will enter the stripper for separation so that MDEA solvent can be reused. The reactions that occur in the absorption and desorption process are as follows:

$$MDEA + CO_2 + H_2O \rightarrow MDEAH^+ + HCO_3^- \tag{2}$$

$$MDEAH^+ + HCO_3^- \rightarrow MDEA + CO_2 + H_2O \tag{3}$$

Simulation Model. Simulation modeling of biomass gasification integrated with water gas shift and carbon capture was conducted in Aspen Plus V12 software. In inputting components, biomass, and ash are defined as non-conventional components. Both will be defined in the component attribute features in Aspen Plus, namely PROXANAL, ULTANAL, and SULFANAL using ultimate and proximate analysis data. The fluid packages used in the gasification simulation are PR-BM, this fluid package can accurately model non-ideal mixtures, mildly polar, light gases, extreme operating conditions, and hydrocarbon gases.[7] Whereas in the carbon capture simulation, the fluid packages used are ELECNRTL because these fluid packages can model liquid-liquid, liquid-vapor, and liquid-solid phase reactions and can model chemical reactions in amine solutions.[8] MIXNC streams were also used to define the structure of biomass and ash streams that were not present in the Aspen Plus database component. The flowchart simulated using Aspen Plus is shown in Figure 2.

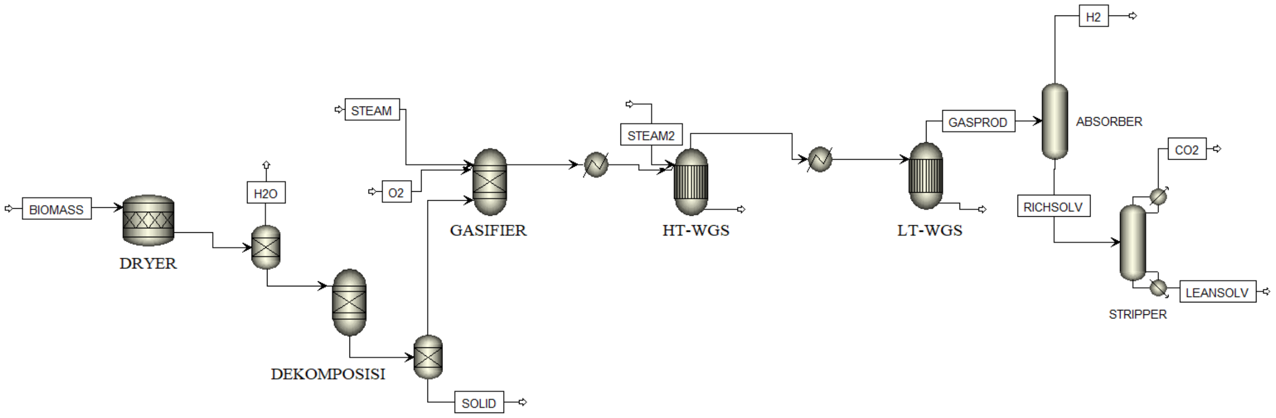

Fig. 2 Flowchart Simulation

Gasification Module. In this gasification simulation, division into three reactors is carried out, by dividing the gasification process into three stages, with different reactors, namely drying, decomposition, and gasification, this is done to facilitate the simulation. The biomass stream will be dried at 150˚C to remove the moisture content in the biomass. this process is carried out using an RStoic reactor, or a reactor that works based on known stoichiometric reactions. After the H2O is separated from the biomass, the feed will proceed to the decomposition process. In this simulation, the decomposition process is modeled with the RYield reactor, this reactor will work based on the input yield value. At this stage, the biomass will be converted into volatile materials (VM) and char. VM will contain carbon, hydrogen, oxygen, and nitrogen, while char contains ash and carbon. The yield value entered in the reactor is based on the proximate and ultimate analysis of the biomass. This reactor works at a temperature of 800˚C with a pressure of 2 bar. The output gas from the decomposition process will then enter the gasifier, to carry out the gasification process. The gasification process runs at 800˚C with a pressure of 2 bar using the RGibbs reactor. This reactor operates based on Gibbs free energy, which will help achieve thermodynamic equilibrium. This simulation also adds stream gasification agents, namely O2 and steam to help the gasification process. This reactor will calculate the syngas composition by minimizing the Gibbs free energy and assuming chemical equilibrium.

Water Gas Shift Module. The gasifier output gas in the form of syngas will directly enter HT-WGS and then LT-WGS, both of these processes use an equilibrium reactor with an operating pressure of 1 barg, and the operating temperatures are 400˚C and 150˚C, respectively. The REquil reactor is simulated by entering the temperature, operating pressure, and entering the reaction that will be carried out in this reactor. With the reactions entered, this reactor will reach equilibrium based on the input conditions. In HT-WGS, steam flow is added, and the addition of steam is intended to supply reactants in the WGS process. This addition is also based on the aim of producing pure hydrogen gas. In purification using the carbon capture process, the CO component needs to be converted into CO_2 so that the carbon capture process can be captured to produce pure hydrogen gas flow.

Water Gas Shift Module. The output gas from the LT-WGS will then enter the absorber for purification. The absorber works at 40˚C operating conditions with a pressure of 20 bar, this tool has 10 trays, with the incoming feed gas in the 10th tray and the solvent in tray 1. This absorption process uses MDEA as a solvent that captures carbon dioxide. The H2 gas product stream or gas stream from the absorber can be directly flowed into storage, or directly used. The liquid flow from the absorber will then be entered into the stripper to desorb CO2 again, this is aimed to recovering the MDEA solvent so that it can be reused. In this process, the stripper operates at a low pressure of 1.15 bar, with 10 trays in the stripper and feed entering on tray 4. CO2 that is successfully separated into the gas phase, while MDEA that is successfully recovered can be reused in the absorption process. In the carbon capture process, simulations are carried out by combining two series, namely the absorber and stripper. Both processes use the same RadFrac Aspen Plus V12 column in the simulation, except that the absorber simulation used is ABSBR1 while the stripper uses FRACT1. RadFrac columns are indeed enabled to handle simulations of absorption, desorption, and distillation.

Methodology. A simulation model developed for the gasification of biomass waste integrated with water gas shift and carbon capture was used to determine the performance of gasification of oil palm empty fruit bunches as lignocellulosic biomass in producing hydrogen gas. Investigations were conducted on the effect of gasification agent ratio and gasification temperature on the composition of syngas produced, and hydrogen production efficiency (HPE). The HPE value is an important parameter in the hydrogen production process, which can be calculated by the following equation:

$$\mathrm{HPE}\ (\%) = \frac{\mathrm{m_{H_2}\ x\ LHV_{H_2}}}{\mathrm{m_{biomass}\ x\ HHV_{biomass}}}\ \mathrm{X}\ 100 \tag{4}$$

mH2 is the hydrogen mass flow rate (kg/hr) based on the simulation results, the LHVH2 is the lower heating value of hydrogen, 120.1 MJ/kg, mbiomass is the mass flow rate of the input biomass, and the HHVbiomass value is the higher heating value of biomass which can be calculated by the following equation:

$$\mathrm{HHV}\left(\frac{\mathrm{Mj}}{\mathrm{kg}}\right) = 0.312\ \mathrm{x}\ (\mathrm{FC}) + 0.1534\ \mathrm{x}\ (\mathrm{VM}) \tag{5}$$

In the carbon capture process, the capture rate (Ψ) is calculated to analyze the simulation results, with the following equation:

$$\Psi = \frac{m_{CO_2}^{cap}}{m_{CO_2}^{in}} \tag{6}$$

This equation calculates the capture rate by comparing the CO2 successfully absorbed with the CO2 entering the absorber.

Validation. Analysis of the simulation baseline for the gasification and carbon capture processes was carried out using calculation parameters adjusted to the results in the reference paper from Safarian et. al [3]. for the gasification process and Antonini et al.[8] for the carbon capture process. In the gasification simulation, several data comparison samples used are the low heating value (LHV) and hydrogen production efficiency (HPE) for each gasification agent, the comparison results are shown in Table 3.

Table 3 Validation of Gasification Simulation Result Value

Gasification Agent	Parameter	Reference	Baseline simulation	Error (%)
Air	LHV	7.05	6.73	4.4
	HPE	33	34.8	5.5
Steam Air	LHV	6.3	5.97	5.2
	HPE	54	53.1	1.6
Steam	LHV	6.28	6.71	6.9
	HPE	69	72	5.4

In the carbon capture simulation that has been carried out, to validate the results of the simulation, a comparison of the results obtained from the simulation with the data provided by the reference journal, namely the value of Ψ (mass of CO2 captured / mass of CO2 entering). The comparison results are shown in Table 4

Table 4 Validation of Carbon Capture Result Value

Parameter	Baseline Simulation	Reference	Error (%)
Ψ	96.1	99.8	3.64

It can be seen from Tables 3 and 4 that the simulation model used shows very good agreement with the experimental results. The deviation of the model results from the experimental value is quantified by a mean absolute error that is less than 7% for all data.

Results and Discussion

Effect of Gasification Agent on Hydrogen Produced. In the simulation of the effect of the gasification agent on the hydrogen gas produced, simulations were carried out by varying the flow rate of the gasification agent. There are three samples used, namely O_2-steam, Air-Steam, and Steam-O_2. In the O_2 and air variations, the steam used is constant at 400 kg/hr, and in the steam variation, the O_2 used is constant at 400 kg/hr as well. The use of mixed steam and O_2 gasification agents in this simulation is because based on Table 2 which displays the gasification reaction shows that the presence of steam and O_2 is needed for the gasification reaction to occur, so in this variation, the steam / O_2 gasification agent is still given as a mixture.

From the results of variations in the flow rate of O_2 and air gasification agents, Figures 3 and 4 show identical graphical results, the most visible difference is only in the N_2 graph. Although the two graphs look identical, the values obtained are not exactly the same. At the ratio point of 0.5, the O_2 gasification agent gets a value of 39.22 Kmol / hr on CO_2, while the air agent gets 40.1 Kmol / hr, as well as other components. Despite having the same flow rate as the O_2 component, the results of the second gasification agent are not exactly the same. This can be caused by the partial pressure possessed by the N_2 component. The difference between these two gasification agents is in the amount of N_2 in the flow, in the O_2 agent the N_2 component moves constantly while in the N2 air agent continues to increase according to the air feed flow which is composed of 79% N_2 and 21% O_2According to the principles of chemical reactions, the partial pressure and concentration of a gas in a mixture can affect other components by altering the reaction equilibrium.

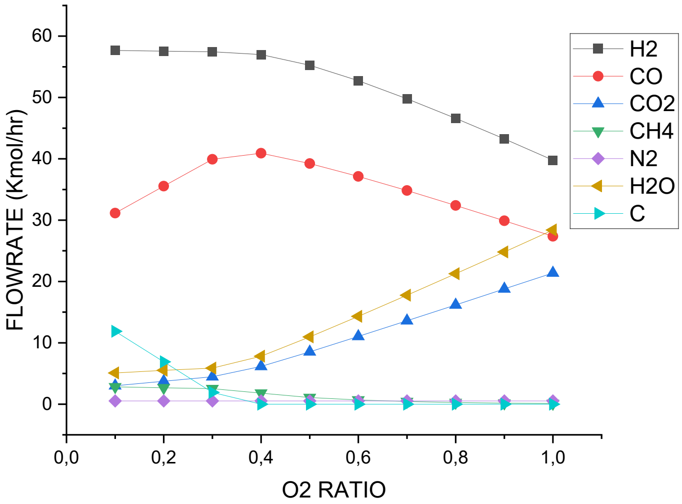

Fig. 3 Effect of O_2-Steam Agent on Gasification Yields

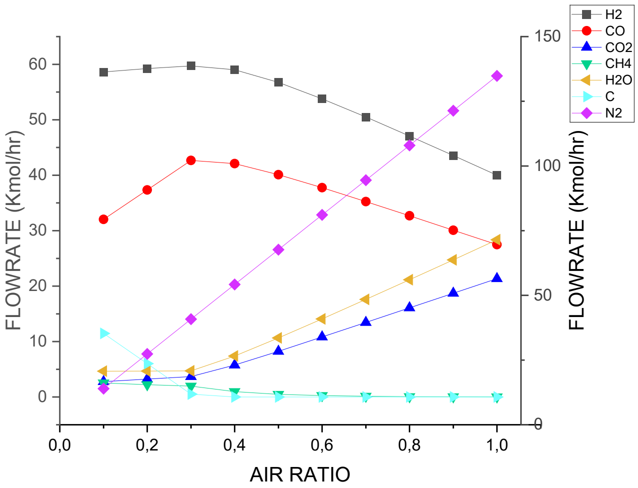

Fig. 4 Effect of Air-Steam Agent on Gasification Yields

In Figures 3 and 4 it can be seen that O_2-based agents, which in this simulation are O_2 and air agents, have a great influence on the movement of C, CO, and CO_2 reactions. This is because O_2-based gasification agents will affect CO and CO_2 products more as described by Basu, Phabir[4] in his research. This can also be explained through reactions complete combustion, partial combustion, bouodard, and CO partial combustion which of the four reactions show how the O_2-based gasification agent functions in this gasification process.

In the simulation results shown in Figure 5, it can be seen how the effect of steam gasification agents on the results of gasification products. At a ratio of 0.4, the trend of the H_2, CO, CO_2, and H_2O components changes. At this point, the graphs of H_2 and CO_2, increased constantly, while CO decreased. This can be explained through reactions of water gas and water gas shift where at points 0.1 - 0.4 the increase in CO and H_2 occurs as in water gas reaction. While at a ratio of 0.4 - 1, the C component has finished reacting so that a water gas shift reaction occurs which causes CO according to, H_2 and CO_2 to increase. The increase in H_2 and CO at a ratio of 0.1 - 0.4 is also supported by the presence of a reforming reaction, where at a ratio of 0.5 CH_4 gas has begun to run out so that it no longer helps the formation of CO and H_2. In the H_2O graph, the increase continues to occur due to the supply of steam gasification agent feed which causes the amount of steam to continue to increase.

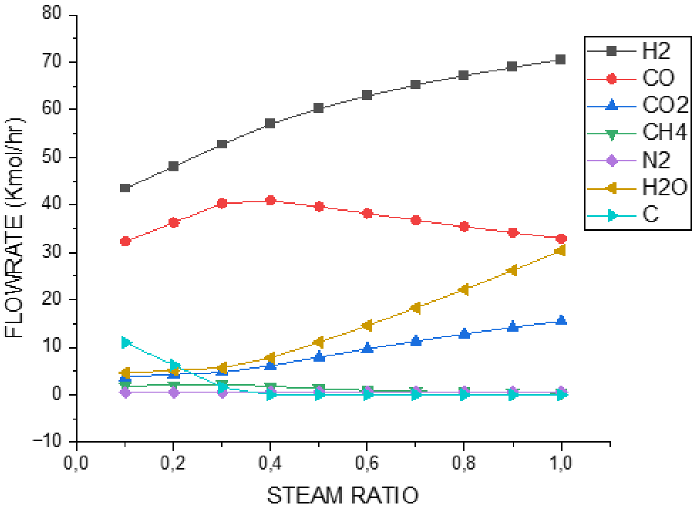

Fig. 5 Effect of Steam-O_2 Agent on Gasification Yields

Based on the results in Figure 5 and water gas, water gas shift, and reforming reactions it can be concluded that the steam gasification agent influences the hydrogen produced. As mentioned by Oliviera, and Matheus.[9] in his research that gasification using steam as a gasification agent has the potential to produce syngas which is rich in hydrogen gas and can reduce CO gas by 30%. This is also in line with the opinion of Basu, and Phabir [4] which states that the use of H_2O as a gasification agent can encourage the formation of hydrogen gas.

Figure 6 shows a decreasing trend in the HPE values for both O_2 and Air agents. The higher the flow rate of the O_2-based gasification agent, the HPE value obtained decreases. This can be explained in the H_2 combustion reaction where hydrogen gas reacts with O_2 to form H_2O, this can happen because if the supply of reactants is too much, an equilibrium reaction will occur which causes the reaction to shift to the right.

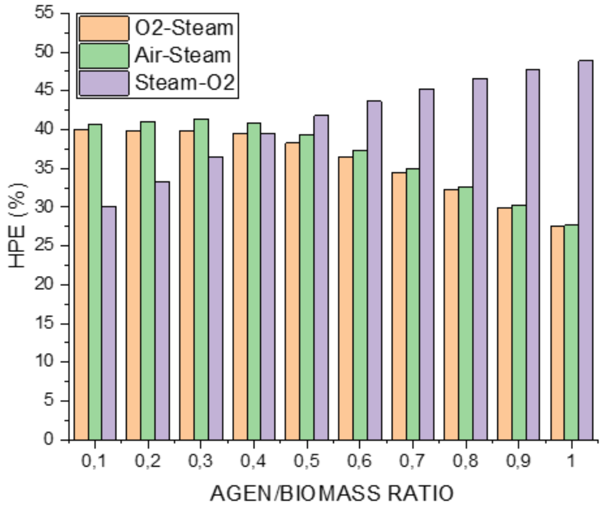

Fig. 6 Effect of Gasification Agen on HPE Value

While in the steam gasification agent graph the graph tends to increase as the number of steam flow rates increases. This is indeed following the theory, mentioned by Basu, Phabir. [4] in his research that the use of H_2O as a gasification agent will encourage the formation of hydrogen gas. This increase also indicates the increase in hydrogen that can be produced in the gasification reaction.

Effect of Gasification Temperature on Hydrogen Produced. In the simulation to determine the effect of gasifier operating temperature on hydrogen produced, simulations were carried out by varying the gasifier temperature. This simulation was carried out to find the most optimal temperature for the gasification process, by looking at the conditions of the six samples in this variation. This simulation uses an O2-Steam gasification agent as an auxiliary agent for the gasification reaction with flow rates of 500 kg/hr and 500 kg/hr.

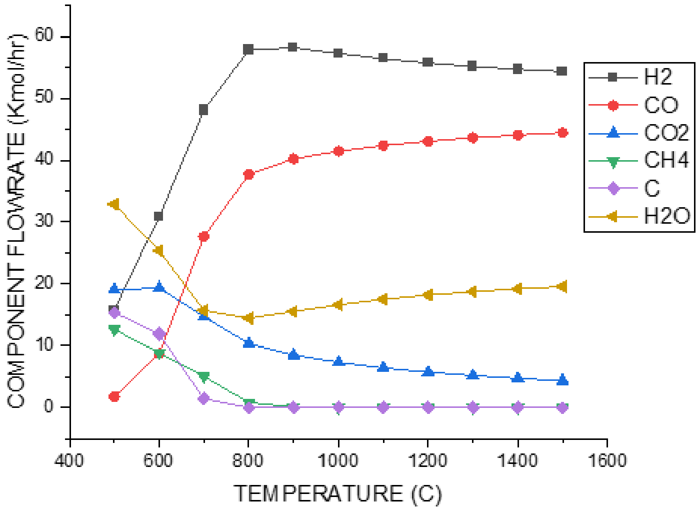

Fig. 7 Effect of Gasifier Temperature on the Gas Produced

Based on Figure 7, shows that 800˚C is the optimum temperature for the gasification process, this is indicated by the temperature after 800˚C all components tend to be constant. From the results obtained, the H_2 and CO components at temperatures from 500˚C to 800˚C experienced an increase in the graph, while the other components were the opposite. This can be explained through the reactions of complete combustion, partial combustion, CO partial combustion, reforming, and H2 combustion.

In the complete combustion, partial combustion, and reforming reactions, it is known that the reaction has a positive delta H value, or it can be said that the reaction is endothermic. So that by increasing the operating temperature to be higher can cause the reaction to shift to the right. As mentioned by Le Chatelier's principle, if the system at equilibrium experiences changes in conditions, the system will adjust to reduce these changes. In reactions that are endothermic, when the temperature is increased, the reaction will shift towards the product.

Likewise, what happens in the CO partial combustion reaction which has exothermic properties, with the high energy received, the reaction shifts toward the reactants. The CO partial combustion reaction also explains why in Figure 7 after 800˚C the CO_2 product continues to decrease while CO increases. The O_2 produced by the CO partial combustion reaction results in a decrease in H_2 as shown in the graph. This can be explained as the H_2 combustion reaction, the occurrence of this reaction is also supported by the increase in the H_2O graph in Figure 7.

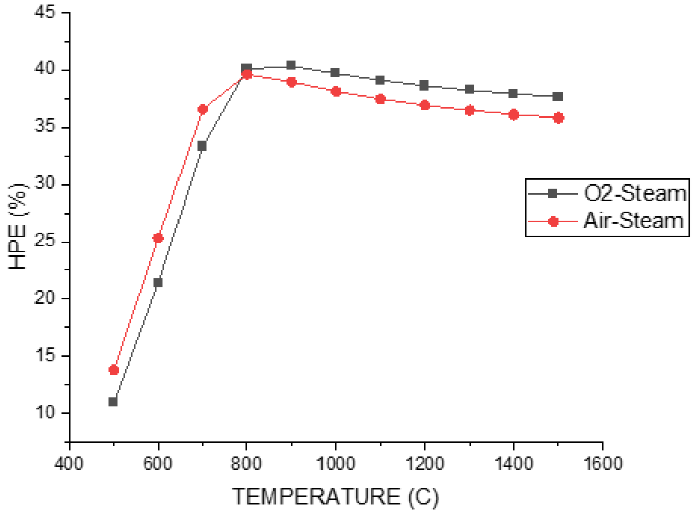

Fig. 8 Effect of Gasification Temperature on HPE Value

Based on the results obtained from the simulation, shows that 800˚C is the optimum temperature for hydrogen gas production, as shown in Figure 8. At temperatures after 800˚C, both graphs decrease, this can be explained by the H_2 combustion reaction. From Figure 8, it can be concluded that 800˚C is the best temperature for producing hydrogen gas with the gasification process.

Effect of Steam Addition in WGS on the Product Produced. In this simulation, the results obtained are intended to determine the most optimal amount of steam that can be used to drive the reaction of changing CO to CO_2. This is because, in the purification process using the carbon capture method, the only compound that can be captured is CO_2, while CO cannot be captured properly. So the use of steam to drive the CO to CO_2 reaction is very important.

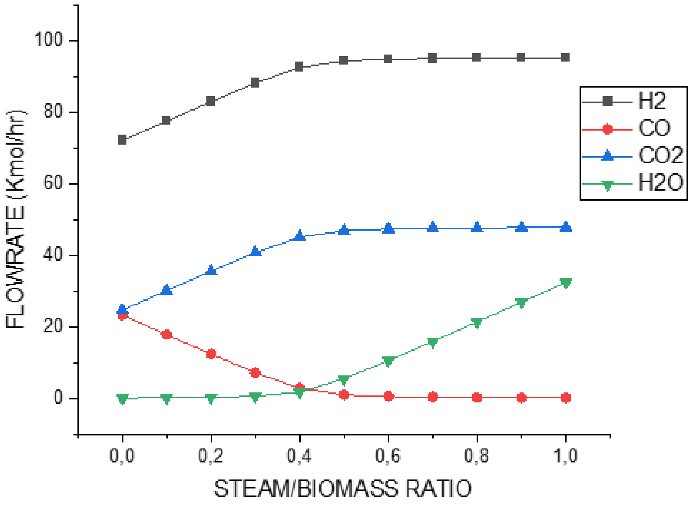

Fig. 9 Effect of Steam on Water Gas Shift Process

Based on Figure 9, it can be seen that H_2 and CO_2 at a ratio of 0 - 0.5 have increased, and CO has decreased. This can be explained by the water gas shift reaction, where CO and H_2O become reactants for H_2 and CO_2. This is also why at a ratio of 0 - 0.5 the H_2O graph does not increase significantly even though the ratio continues to grow. The water gas shift reaction can also explain why at a ratio of 0.5 to 1, the H_2 and CO_2 gas graphs no longer change, because the CO has finished reacting and causing H_2O to increase rapidly. Based on the results obtained from the simulation, the selection of a ratio of 0.6 is the best, because at this ratio CO has reached point 0 and the amount of H_2O in the product gas is reduced.

Effect of Solvent Flowrate on CO_2. In the simulation to determine the effect of methyldiethanolamine (MDEA) solvent flow rate on CO_2 that can be captured, simulations were carried out by varying the MDEA solvent flow rate. Based on the results shown in Figure 10, the resulting graph experiences a constant increase and the increase stops at a ratio of 2 MDEA/ CO_2. At an MDEA/ CO_2 ratio of 2, the value achieved is 99.9%, indicating that at this ratio MDEA can capture 99.9% of the CO_2 in the gas stream. This result is also in accordance with the statement of Budzianowski, W.M. [10] which states that the ratio used by MDEA in the carbon capture process is 2:1 to 4:1 depending on the conditions. In this simulation, with the operating conditions suggested by Antonini, Cristina.[8] in their research, making the ratio 2:1 mol MDEA/ CO_2 can capture 99.9% of CO_2 in the flow

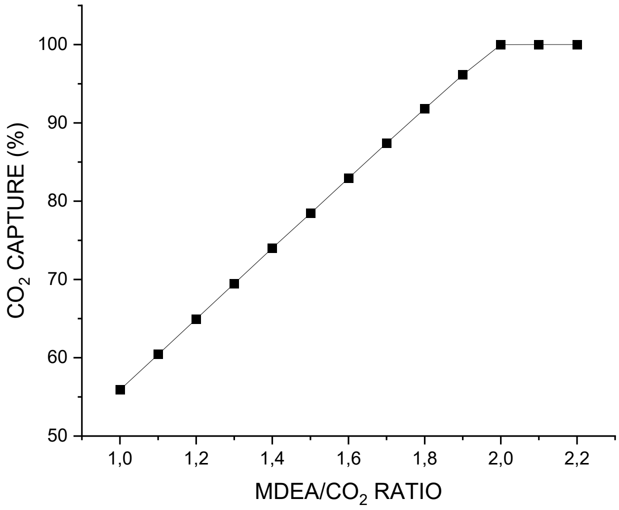

Fig. 10 Effect of MDEA Flowrate on CO_2

In this simulation, the MDEA solution used is very large, this will affect the financial factor if it must continuously supply MDEA solution. Because of this, there needs to be recovery of MDEA solvent that has captured CO_2 so that MDEA can be reused to capture CO_2. In this simulation, a Stripper tool is added to desorb CO_2 from the MDEA solution, as shown in Figure 10. In the simulation, the Stripper is operated under pressure conditions of 1.15 bar according to data obtained from Antonini, Cristina.et al. [8] From the simulated results, the Stripper can recover MDEA by separating 99% of the captured CO_2.

The achievement of desorption results is influenced by the operating pressure conditions. In the desorption process, the pressure conditions used are inversely proportional to the absorption process, in the simulation, absorption is carried out at a pressure of 20 bar while desorption is carried out at a pressure of 1.15 bar. In the MDEA absorption reaction, pressure affects the reaction, at high pressure the reaction will tend to shift towards the right, while conversely at low pressure the reaction will shift towards the left. With these pressure conditions, it allows the simulation to get good results.

Conclusions

In this study, a simulation model using Aspen Plus was designed for the gasification process integrated with a water gas shift reactor and carbon capture for hydrogen gas production. Oil Palm Empty Bunch as lignocellulosic biomass is the feedstock in this study. This simulation model was used to investigate the effect of gasification agent flow rate, the effect of gasifier temperature on syngas produced, and the HPE value. Investigations were also carried out on the addition of steam in the WGS reactor and the effect of solvent flow rate in capturing carbon dioxide.

The results of the simulations that have been carried out show that the flow rate of O_2 and H_2O-based gasification agents has an influence on gasification products. The use of O_2 will help form CO and CO_2 while the use of H_2O will help form H_2 and CO_2. The use of an O_2-Steam gasification agent is the best choice in this simulation because it is easier to purify the simulated H_2 gas. The flow rate of 500 kg/hr O_2 and 500 kg/hr H_2O is the flow rate of choice because at this flow rate, the impurity product has been completely reacted and the hydrogen produced is quite a lot. The temperature of the gasification reactor also affects the gas products produced, the increase in operating temperature helps gaseous products such as CO_2 and H_2 to form and removes gases such as CH_4. In this simulation, 800˚C was found to be the most optimal temperature in terms of products produced and energy consumption.

The addition of steam to WGS reactor is an important process in the gasification process combined with the carbon capture process. The addition of steam makes it easier for CO_2 to form on WGS so that it will be easily absorbed. In the simulations that have been carried out, it is found that the ratio of 0.6 steam/biomass is the best choice because at this ratio CO has finished reacting into CO_2.

The increase in the MDEA/CO_2 ratio can increase the ratio of CO2 captured in the absorption process. In this simulation, it is found that the ratio of 2:1 mol MDEA/CO_2 is the best ratio in the absorption process using MDEA because it can capture 99.9% CO_2 from the gas stream.

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