Simulation for Hydrogen Production from Palm Waste via Supercritical Gasification Using Concentrated Solar Energy

by

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15666

Dissertation submitted in partial fulfillment of

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Universiti Teknologi PETRONAS,

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CERTIFICATION OF APPROVAL

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Approved by,

____

(Dr. Nor Erniza Binti Mohammad Razali)

UNIVERSITI TEKNOLOGI PETRONAS

BANDAR SERI ISKANDAR, PERAK

September 2015

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the reference and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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NORMI IZATI BINTI MAT NAWI

ABSTRACT

Simulation for Hydrogen Production from Palm Waste via Supercritical Gasification Using Concentrated Solar Energy is actually one of the alternatives used for hydrogen production instead of using the experimental method. Hydrogen has the potential as an alternative clean energy. The relevancy of choosing palm waste as the source of biomass is because it can be considered as the most abundant waste in Malaysia with the production of 70 million tons annually. The purpose for this project is to develop a simulation for the hydrogen production from palm waste using Aspen Hysys. Besides, this work also includes parametric studies on the developed simulation to determine the effect of temperature, pressure and steam to biomass ratio to the hydrogen yielded. Empty Fruit Bunch (EFB) from palm waste has been used as the feed for the simulation. It is found that increment in temperature and steam to biomass ratio promotes hydrogen production whereas increment in pressure resulted in decrement of hydrogen yielded. The results are compared with published literatures on the different systems and the comparison shows that the results are in agreement to some extend due to the different basis.

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CHAPTER 1

INTRODUCTION

1.1 Background Study

Due to the energy crisis and environmental problems related to the burning of fossil fuels as the main source of energy, the utilization of hydrogen as a clean and sustainable energy carrier is becoming more attractive and popular among the researchers. Oil palm is one of the major economic crops and Malaysia alone produces about 47% of the world's palm oil supply which can be considered as the world's largest producer and exporter of palm oil. Currently, interest in utilizing the oil palm waste is continuously increasing and one of it is the production of hydrogen from the palm waste. Since hydrogen production from biomass or palm waste is a clean, efficient energy source and sustainable raw material, it is expected to take a significant role in future energy demand [1].

In order to produce the hydrogen from the biomass or palm waste, gasification process had been used to increase the efficiency of the production. Biomass gasification is principally the conversion of biomass into a combustible gas mixture which is normally called "producer gas" at high temperature. The resulting gas mixtures also called synthesis gas or syngas. Due to the development of technologies, hydrogen production in supercritical water has been introduced. The properties of water displayed beyond critical point plays significant role for chemical reactions. A hydrogen rich-gas can be formed with almost complete conversion of the feedstock of biomass into gas at temperature of 600°C in supercritical water [1]. Since the operating temperature of the process is quite high, the concentrated solar energy is proposed to be used as the external heat resource. This is because it is claimed that solar energy is the best alternative source for heat energy since it is considered as most the abundant renewable energy source on the earth.

1.2 Problem Statement

Recognizing the crisis of fossil energy and the increasing of environmental pollution caused by the excessive burning of fossil fuels, it is significant to exploit the new, clean and sustainable energy source. It has been identified that the main cause of global warming is from the progressive emission of greenhouse gas (GHG). The main source of GHG emitter is from power-generating plants running of fossil fuels [2]. That is one of the reason hydrogen productions from biomass or palm waste is introduced.

Palm waste is also one of abundant waste in Malaysia since Malaysia is considered as the largest producer of palm oil which will give a lot of residue. Supercritical gasification is a hydrogen production process from biomass which acquires quite high temperature which needs more power to meet the reaction condition. The biomass gasification system was very complicated, and it was difficult to operate practically [3]. So, a simulation using Aspen Hysys is developed to make it simpler.

1.3 Objective and Scope of Study

The objectives of this project are as follow:

1. To develop a simulation for hydrogen production from palm waste using Aspen Hysys via supercritical gasification using concentrated solar energy.
2. To perform parametric studies which are the effect of temperature, pressure and steam to biomass ratio.

CHAPTER 2

LITERATURE REVIEW

2.1 Hydrogen production from palm waste

The percentage of biomass produced from oil palm has increased tremendously since 1980 until recently, contributed by the expansion of the crop plantation due to the high demand for palm oil. This abundant palm waste can be converted through supercritical gasification in order to produce hydrogen [2]. In addition, oil palm topped the ranking in term of fruit crops production for the year 2007 with 36.90 million tonnes produced or 35.90% of the total edible oil in the world. Figure 2.1 shows the expansion of oil palm cultivation area in Malaysia from the year of 1960 until 2015 [9]. With the cultivation area of 5.39 hectares, Malaysia can be considered as one of the biggest producer of palm oil plant. From the oil palm production, there is only 10% of oil extracted from the palm while the rest 90% is biomass. Components or parts of oil palm biomass residue that can be used for supercritical gasification process in order to produce hydrogen are empty fruit bunch (EFB), mesocarp fibler, palm kernel shells, palm tree trunks and fronds [2]. Hence, hydrogen production from palm solid residue (PSR) using thermochemical process is a perfect approach for waste-to-well strategy in palm oil mills in Malaysia [5].

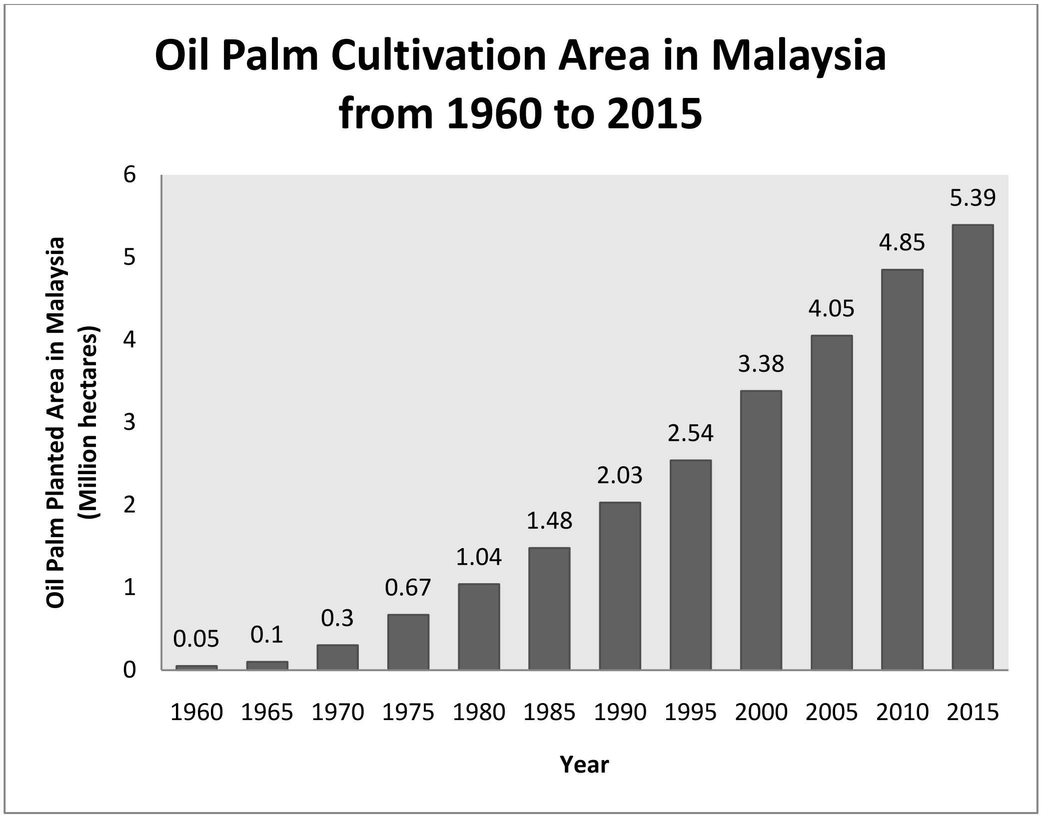

Figure 2.1 Expansion of oil palm cultivation area in Malaysia from year of 1960 to 2015

As reported by Gutierrez et. al, [10], EFBs comprises 9% from the total oil palm industry's 90 million tons of renewable biomass leftover after extraction at oil mills. Harnessing EFB as industrial energy feedstock either through combustion or as ethanol potential, may promote replacement of fossil fuel for industrial use and accordingly deal with the issue of waste management since the density of EFB makes it uneconomical to transport and manage [11]. EFB is a solid residue produced in the highest amount as a by-product in palm oil processing [12].

A growth in energy generation capacity will be essential now since the increasing trend in world's energy need is expected to continue in the future. In order to meet the world's energy needs, finding more secure, clean and diversified energy sources could be a successful strategy to reduce and eliminate greenhouse gas (GHG) emission. Compared to other alternatives, hydrogen has a large number of advantages and it could be used to reduce the dependency on oil and gas industries as the source of energy. Although hydrogen is not a primary source of energy, it becomes an attractive energy carrier when split from other elements such as carbon, nitrogen and oxygen by using a source of energy [4]. Hydrogen utilization is free of toxic gases formation as well as carbon dioxide (CO_2) emission [5].

According to Abbas et. al, hydrogen combustion provides energy based on basis with lower heating value, which is 2.4, 2.8 and 4 times more than that of methane, gasoline and coal respectively [6]. The current scenario of hydrogen utilization indicates that it has not been seriously taken into consideration in the energy scenario of the world yet [5]. Nevertheless, the future widespread utilization of hydrogen is likely to be in the transportation system, where it will eliminate toxic emissions. Hydrogen fuel cell (HFC) demonstrated three times more efficient than engines fuelled by gasoline [7].

Hydrogen production technologies can be divided into two categories which are non-renewable (fossil fuels) and renewable resources. Renewable hydrogen production technologies related to biomass utilization includes gasification, pyrolysis and biological fermentation [8]. Figure 2.2 shows the existing techniques that currently have been used in order to produce hydrogen. The production of hydrogen from biomass can either be via thermochemical process or biological process. The thermochemical process includes the gasification and pyrolysis while via biological process, the available techniques are dark fermentation, photo-fermentation and bio-photolysis [5].

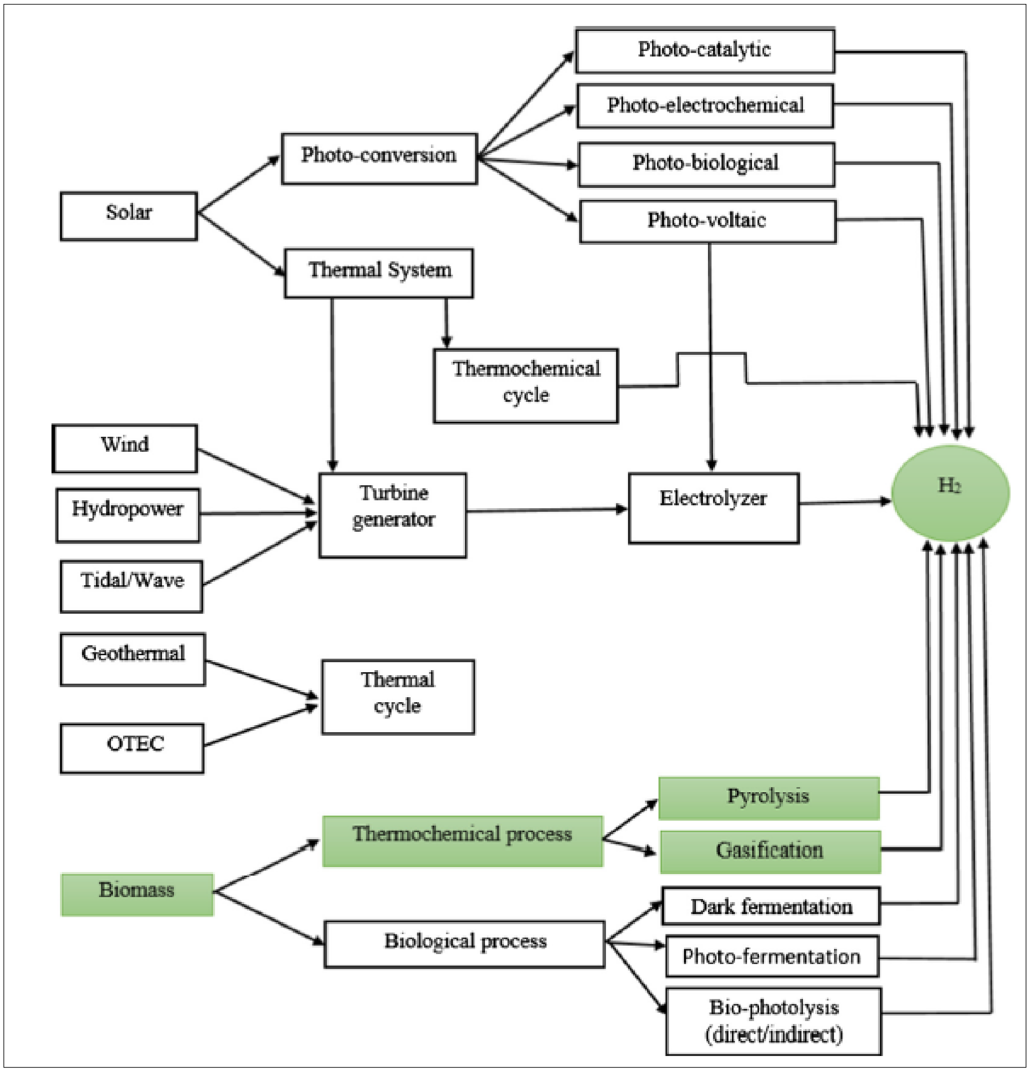

Figure 2.2 The existing technique for hydrogen production

2.2 Hydrogen Production via Supercritical Gasification

Generally, gasification is a high-temperature partial oxidation process whereby a carbon source such as natural gas, carbon and biomass is broken down into carbon monoxide, hydrogen, carbon dioxide and hydrocarbon molecule like methane using gasifying agents. Gasification also converts biomass into a gaseous fuel by heating in a gasification medium such as air, oxygen or steam. Unlike combustion where oxidation is substantially complete in one process, gasification converts the natural chemical energy of the carbon in the biomass into a combustible gas in two stages [13].

Based on Cruse [14], hydrothermal gasification for hydrogen and methane generation process can be divided into;

1) Catalyzed aqueous-phase reforming of light oxygenates originating from biomass to produce hydrogen.
2) Catalyzed gasification to produce methane.
3) Supercritical gasification with or without the addition of a heterogeneous catalyst to produce hydrogen.

Supercritical gasification is the gasification process conducted above the critical point of water and biomass. Liquid and gas phase of water demonstrate various properties below the critical point. However, these properties become alike as the temperature increases [5]. As shown in Figure 2.3, the ideal condition for supercritical water to be form is when the temperature is higher than 374 °C and pressure above 221.1 bars. A large portion of biomass is wet biomass which containing up to 95% water and this wet biomass may cause high drying costs if classical gas-phase gasification process is used [15]. Thus, more attention has been paid to the supercritical gasification method for hydrogen production since it can advantageously avoid the high-drying cost.

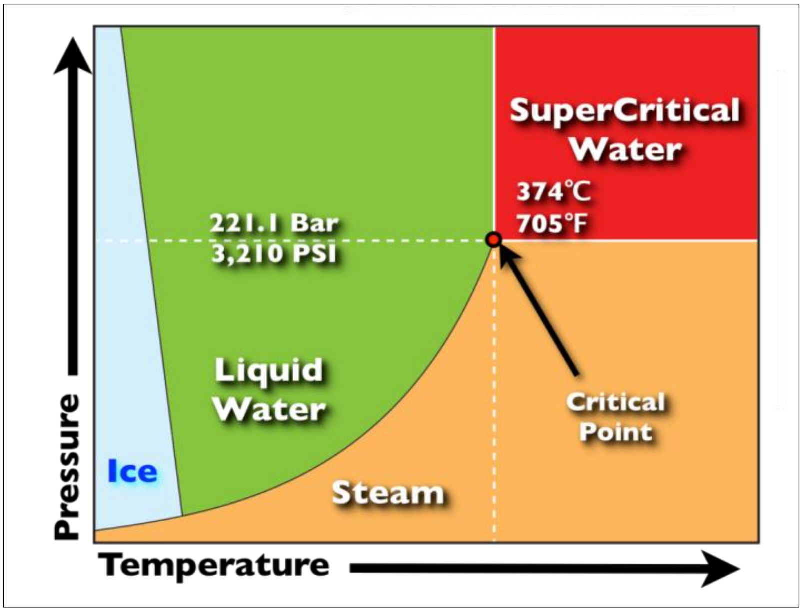

Figure 2.3 Water profile at supercritical condition

Based on a research conducted by Hosseini et. al, (2015), the annual oil palm fruits production in Malaysia is approximately 100 million tonnes which the solid waste of the fruits is capable to generate around 1.05 x 10^{10} kgH_2 (1.26 EJ) through supercritical water gasification (SCWG) process. The ratio of energy output to energy input of SCWG process of PSR is about 6.56 which indicate the precedence of SCWG to transform the energy of PSR into a high energy end product. For the process of generating hydrogen from the PSR, the most significant difficulty for its direct combustion is the high moisture content of PSR. Thus, it is an advantage of applying thermochemical reactions and the highly moisturized PSR is utilized directly in SCWG without application of any high drying process. Execution of proper approaches could lead Malaysia to supply about 40% of its annual energy demand by hydrogen yield from SCWG of PSR [5].

In hydrothermal gasification, this biomass does not need to be dried with a high expenditure. However, water is needed in the process as a reactant and reaction medium. High gas yields are reached at comparably low temperatures with a very low formation of undesired products like tars and coke due to the rapid hydrolytic decomposition of carbohydrates and the good solubility of the intermediate products under reaction conditions [14].

The chemistry reaction of the supercritical gasification is often claimed as complicated and complex because it involves of multiple reactions that occuring simultaneously and producing gaseous and liquid mixture [15]. According to Kelly et. al, there are only three(3) main reactions in the supercritical gasification of biomass. They are steam reforming, water gas shift reactions and methanation. The reactions are as follow;

$$\text{Biomass}+H_2O \rightarrow H_2+CO, \quad (1)$$

$$CO+H_2O \leftrightarrow CO_2+H_2, \quad (2)$$

$$CO+3H_2 \rightarrow CH_4+H_2O. \quad (3)$$

For the first reaction which is the steam reforming, the biomass reacts with water at its supercritical condition in the steam-reforming reaction in order to produce gaseous mixtures of hydrogen and carbon monoxide. Then, for the second reaction, the carbon monoxide produced from the first reaction will undergo an inorganic chemical reaction termed as water–gas shift reaction with water to produce more carbon dioxide and hydrogen. It is possible that the carbon monoxide produced from the first reaction between water and biomass caused the equilibrium of the water gas shift reaction to shift to the right, ultimately producing more hydrogen in the end product. In the last reaction, carbon monoxide will react with hydrogen from previous reaction and methanation will occur to obtain methane and water as its end product.

Chen et. al studied that the advantages of using supercritical gasification are as follows [16]:

1) The formation process of CO_2 is neutral from the aspect of life time cycle,

2) Cost-effective compared to traditional gasification processes as the wet biomass does not to be dried first,
3) CO_2 can be easily separated from H_2 as CO_2 has high solubility in high pressurized water at room temperature.
4) Gaseous product is clean and the effluent can be used as fertilizer.

Currently, there are some researches that are focusing on varies types of gasification in order to contribute for the hydrogen production and to determine the best method to produce the gas either via experiment or simulation. Some researches from literature reviews has been tabulated in Table 2.1.

Table 2.1 Experiment and simulation of gasification from literature reviews

Author	**Title**	**Method of Study, Biomass Studied, Gasifying Agent**	**Limitation**
Chen et. al [16]	Hydrogen Production by Biomass Gasification in Supercritical Water using Concentrated Solar Energy: System Development and Proof of Concept	• Experiment ▪ Corn, meal, wheat stalk ▪ Steam	Used experimental method which is costly, time constrained, limited parameters study.
Chiew et. al [17]	Simulation of Hydrogen Production From Biomass via Pressurized Gasification using iCon	▪ Simulation using iCON ▪ Biomass ▪ Steam	Will be costly since the biomass need to be dried first.
Inayat	Process Modeling for	▪ Process	The process used is

et. al [18]	Parametric Study on Oil Palm Empty Fruit Bunch Steam Gasification for Hydrogen Production	Modeling using MATLAB ▪ Oil palm EFB ▪ Steam	traditional gasification which mean that the biomass need to be dried first.
Liao & Guo* [19]	Concentrating Solar Thermochemical Hydrogen Production by Biomass Gasification in Supercritical Water	▪ Experiment ▪ ethylene glycol, glucose ▪ Steam	Used experimental method which is costly, time constrained, limited parameters study.

2.3 Concentrated solar energy as the heat resource

High temperature and pressure are required to meet the minimum reaction condition of supercritical gasification. Therefore, the high operating cost has become the biggest obstacle to the development of this technology. Hence, the using of concentrated solar energy as the source of heat for supercritical gasification is can realize a low-cost and high-efficiency hydrogen production [16].

According to the Le Chatelier principle, the formation of hydrogen predominates over that of CH_4 at high temperatures. The pressure dependence of the gas yields is far less pronounced. The yield of hydrogen decreases with increasing pressure, whereas that of CH_4 increases. This shift of the gas composition due to the increase in pressure is attributed to the smaller volume increase in CH_4 formation as compared to hydrogen formation [14].

Solar radiation is one of the promising renewable energy and is abundant on earth. Therefore, it becoming a hot topic for researchers to study on how to achieve high efficiency, low cost, large scale solar energy storage and utilization since the characteristic of solar radiation is such not being available for all times, low irradiation density, discontinuous and dispersion [19]. There are many advantages and good prospect of the proposed thermochemical process. However, many challenges should be dealt with in the future, such as designing high-efficiency reactor for the biomass supercritical gasification process using concentrated solar energy and continuous gasification of real biomass with high dry matter [16]. More to the point, solar steam gasification of biomass uses concentrated solar energy to convert solid biomass feedstocks into high-quality syngas, mainly H_2 and CO, applicable for power generation in efficient combined cycles and fuel cells, or for processing of liquid biofuels [20].

Based on research that had been done by Chen et. al [16], characteristics of the gasification of biomass by using the concentrated solar energy as the source of heat has the following characteristics. The first one is, in term of solar input, calorific value of the biomass is upgraded in an amount equal to enthalphy change of the reaction. Second, the whole process is sustainable. Third, solar energy is converted to chemical energy, which overcomes the principal drawbacks of solar energy.

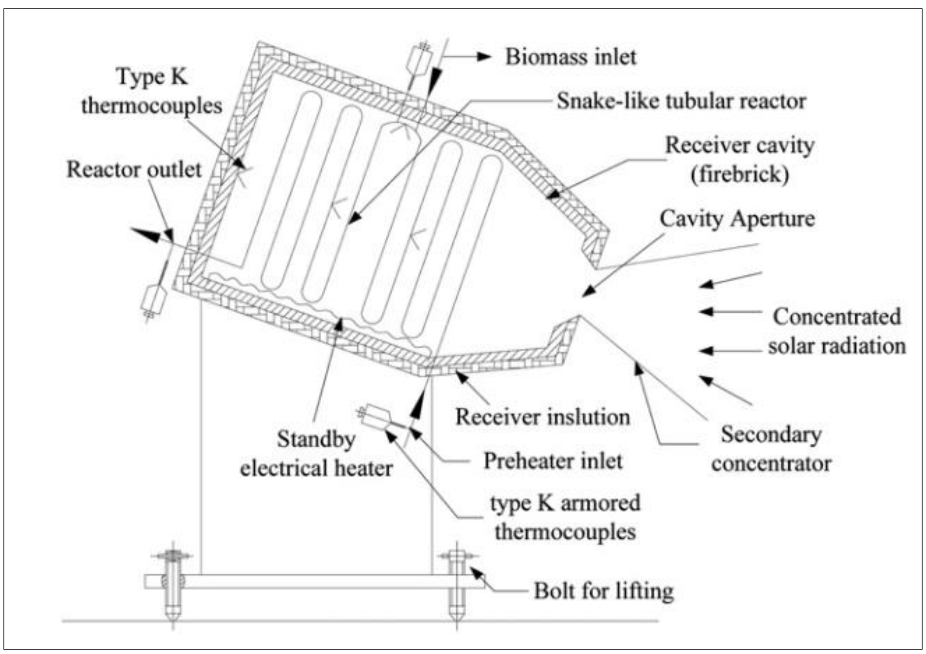

Figure 2.4 Schematic diagram of the solar receiver

Figure 2.4 illustrates the schematic diagram of solar receiver which are suitable to be applied for supercritical gasification of biomass in order to produce hydrogen recommended by Chen et al. [16]. From the figure, it shows that the solar receiver is a square cavity-type receiver made up of firebrick with 400 m inner length, 400 mm width and 400 mm height, and it is insulated with aluminosilicate fiber cotton as heat insulation materials. In the receiver cavity, a snake-like tubular reactor was mounted. It is made of SS 316 stainless steel with 10 mm o.d.×6mm i.d. × 18 m length. The reactor was designed for temperature up to 927 K and pressure up to 30 MPa, it was exposed to concentrated solar irradiation entering through the aperture of cavity and IR irradiation emitted by the hot cavity walls.

Figure 2.5 shows the flow chart of supercritical gasification of biomass driven by solar energy as suggested by Liao & Guo [19]. The pre-heated supercritical water mixes with the biomass loading stream prior to entering the main reactor for rapid-heating supercritical water gasification of biomass. The product stream was then separated into liquid and gas phases.

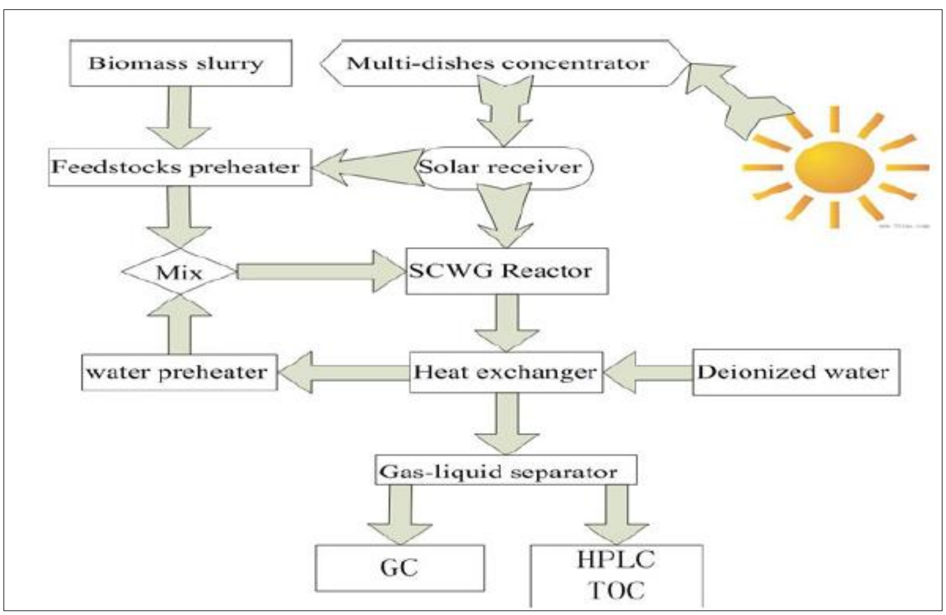

Figure 2.5 Flow chart of supercritical gasification of hydrogen production from biomass using solar energy

According to Zeidan et al. [21], before applying the system to industrial scale, it is crucial to evaluate the sunshine period for specified location by knowledge of the day number of the year and determine the instantaneous value of total radiation on tilted surface during the sunshine period to study the solar radiation module.

CHAPTER 3

METHODOLOGY & PROJECT WORK

3.1 Project Methodology

Methodology is a term which can be best used to explain the analysis of principles or rules and methods employed by a discipline. It can also be used in reference to study or description of methods that have been applied to a particular study.

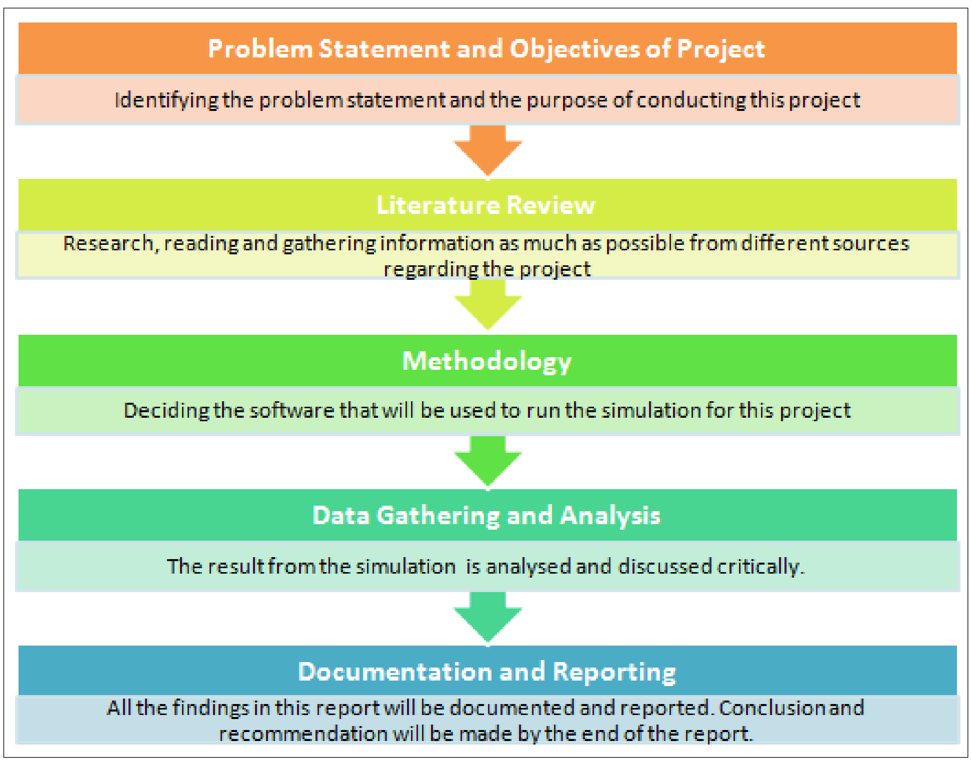

Figure 3.1 Process flow of the overall project

The first phase of this project is started by selecting the related literatures mainly about the hydrogen production from palm waste or biomass via supercritical gasification and using concentrated solar energy as the source of heat for the hydrogen production technique. All the results obtained will be documented and result trending will be analyzed. A brief justification and comparison with other research paper will be made in order to come out with a proper conclusion for this project. The process flow for this research project illustrated in Figure 3.1. The process must be followed so that the objectives of the study can be successfully achieved.

Table 3.1 Gant chart and key milestone of the project

No.	Week / Details	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	Research Work and Literature Review															
2	Developing Simulation															
3	Analyzing result from simulation															
4	Report Writing															
5	Submission of Progress Report								○							
6	Pre-SEDEX											○				
7	Submission of Draft Report											○				
8	Submission of Dissertation Report (Soft Bound)												○			
8	Submission of Technical Paper												○			
9	Viva Oral Presentation													○		
10	Submission of Project Dissertation (Hard Bound)															○

○ Milestone

Table 3.1 depicts the Gantt chart that had been constructed before the project started to illustrate the schedules of the project. Gantt chart shows the start and finish dates of the terminal elements and summary elements of a project.

3.2 Software for Simulation

The simulation for this project will be developed using ASPEN HYSYS. It helps mainly in selecting and defining pure components, assigning a property package for carrying out flash and physical properties calculations, and defining reactions which can be embedded into any unit operation during the simulation process. Aspen HYSYS is a market-leading process Simulation tool for conceptual design, optimization, business planning, asset management, and performance monitoring for oil and gas production, petroleum refining, gas processing and others. ASPEN HYSYS is powered by Visual Basic which is mostly used for software development [22]. The result trend will be analyzed and a proper justification will be made.

3.3 Biomass Feedstock

As for the biomass feedstock, empty oil palm fruit bunch (EFB) has been used for this supercritical gasification process due to its availability throughout the year [18]. Based on research done by Laohalidanond et. al [23], the molecular weight of EFB is 97.7 kg/kgmol while the molecular formula of EFB is $C_{3.4}H_{4.1}O_{3.3}$ based on 1 kg of biomass. Table 3.1 shows the chemical component percentage of empty fruit bunch of palm oil [24, 25].

Table 3.2 Elementary analysis of empty fruit bunch (EFB) from oil palm

Component	Proportion
Proximate analysis (wt%)	
Cellulose	59.7
Hemicellulose	22.1
Lignin	18.1
Ultimate analysis (wt%)	
C	48.79
H	7.33
N	0.00
O	36.30
S	0.68

3.4 Simulation Description

Before developing the simulation of supercritical gasification for hydrogen production, few assumptions has been made in process modeling based on available data and information collected from literature reviews to proximate and simplifies the simulation model.

The assumptions are as follows:

- Palm waste or biomass is represented as EFB with the molecular formula of $C_{3.4}H_{4.1}O_{3.3}$
- The gasification product gas contains CO_2, CO, H_2 and CH_4
- Tar and ash formation are negligible and hence do not participate in chemical reaction because the consideration of tar and ash content may lead to an increasing amount of error for final product gas composition [18].
- It is assumed that the temperature distribution is uniform and perfect mixing in the gasifier [26]

There were two (2) feed streams for the process which were the biomass or EFB stream and water stream. The mass flow rate of EFB input was set to 100 kg/h while the flow rate of water was set to be 900 kg/h in which give the feed total of 1000 kg/h.

Figure 3.2 shows the flow of the process while Figure 3.3depicts the schematic flowsheet diagram generated from Aspen Hysys. The process started with the mixing of the feeds stream (EFB and H20) using mixer MIX-100. The feed streams were set to 1000 kg/h with the atmospheric pressure (1 bar) and temperature of 25 ^oC. Then, the stream from the mixer, stream 1 was being pressurized to reach 300 bars and was heated to 700 ^oC. As for the heating process, the concentrated solar energy was being used as the process heat resource. The solar collector was modeled by simple process-utility heat exchangers in this simulation. It should be noted that, any process fluid pressure drops in this exchanger was neglected for the simplicity [27]. The reactor (GBR-100) has been modeled using RGIBBS which is developed on the principle of minimizing the Gibbs free energy [28]. The stream leaving the reactor carries the synthesis gas (SYNGAS) then is cooled until 20^oC before entering the phase separator for the separation of gas from water. Water from the separator can be recovered and recycled.

By using Aspen Hysys, simulations were performed at various operating conditions in order to study the effect of parameters to the hydrogen production. The different temperatures (500, 600, 700, 800 and 900 ^oC), pressure (250, 300 and 350, 400, 450 bar) and steam to biomass ratio (2 until 3) has been used [28]. The ranges of operating conditions are chosen based on the upper and lower limit used by researchers. When the temperature was varied from 500^oC to 900^oC, the pressure was maintained at 300 bars and 10% of biomass concentration. As the pressure was varied, the temperature was set at 700^oC with 10% of biomass concentration. The temperature and pressure was set at 700^oC and 300 bars as the steam to biomass ratio was varied.

3.4.1 Block Diagram of process

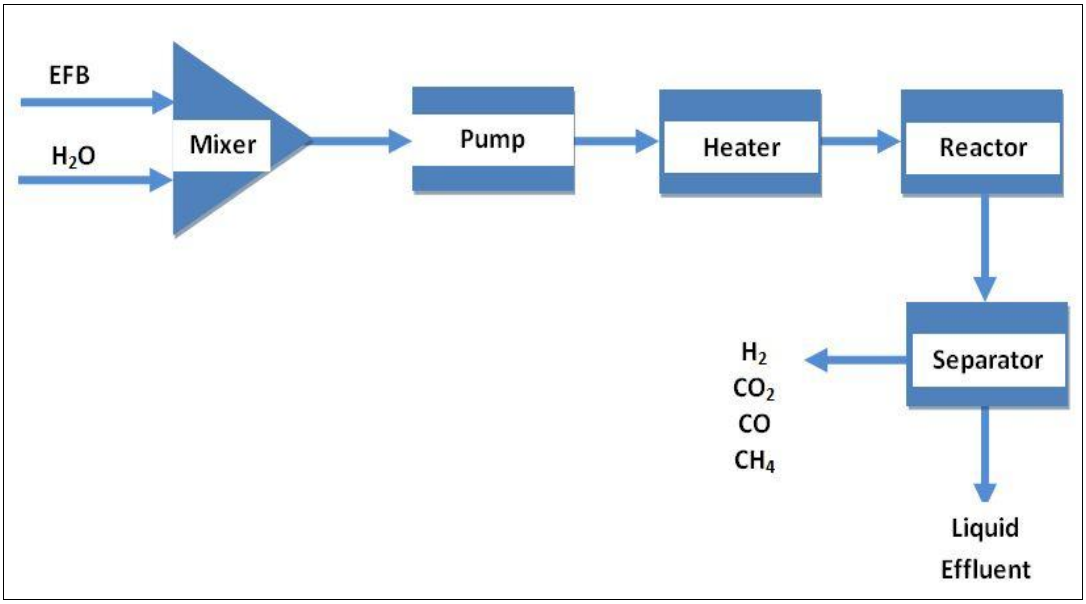

Figure 3.2 Block diagram for supercritical gasification process

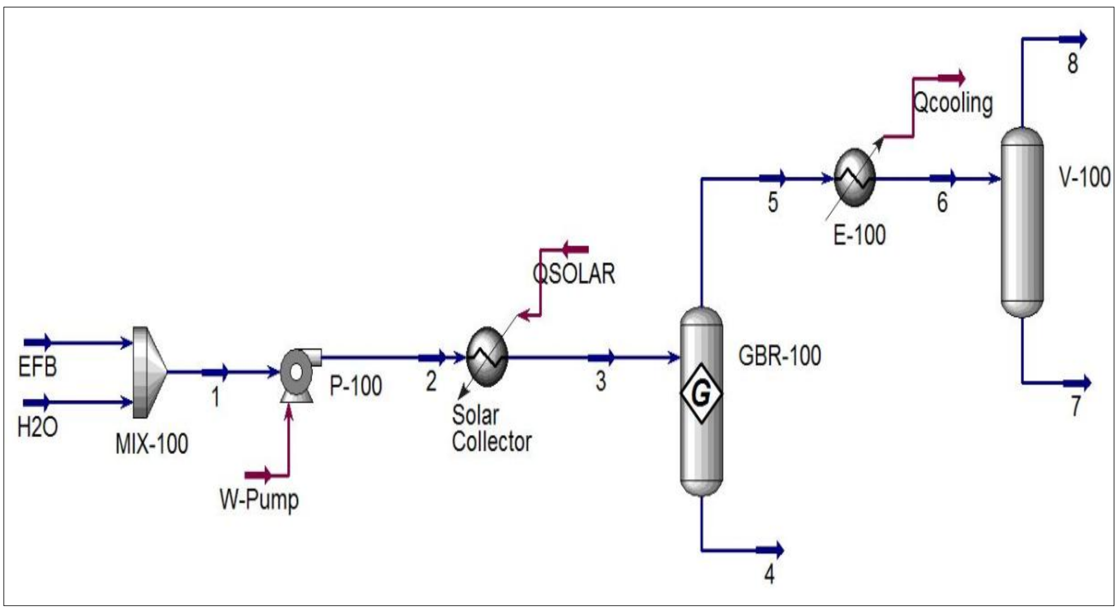

Figure 3.3 Schematic Flowsheet Diagram from Aspen Hysys

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Effect of Temperature

For gasification, temperature is claimed as the most dominating parameters that affect the amount of H_2 yielded [29]. The operating condition was varied from 500 to 900 °C while keeping the pressure constant at 300 bar and the concentration of EFB is 10% [28]. As observed from Figure 4.1, the percentage of H_2 increased with the increased of operating temperature. Based on Le Chatelier's principle, higher temperatures favor the reactants in exothermic reactions and favor the products in endothermic reactions. Thus, the increasing of temperature will encourage the endothermic reforming reaction of hydrocarbon, which then increases the concentration of H_2 [30]. A higher temperature could limit the methanation reaction and promote a water gas shift reaction, which leads to low CH_4 formation [31]. Figure 4.2 shows the increasing amount of hydrogen yielded in g for 1kg of EFB with the increment of temperature.

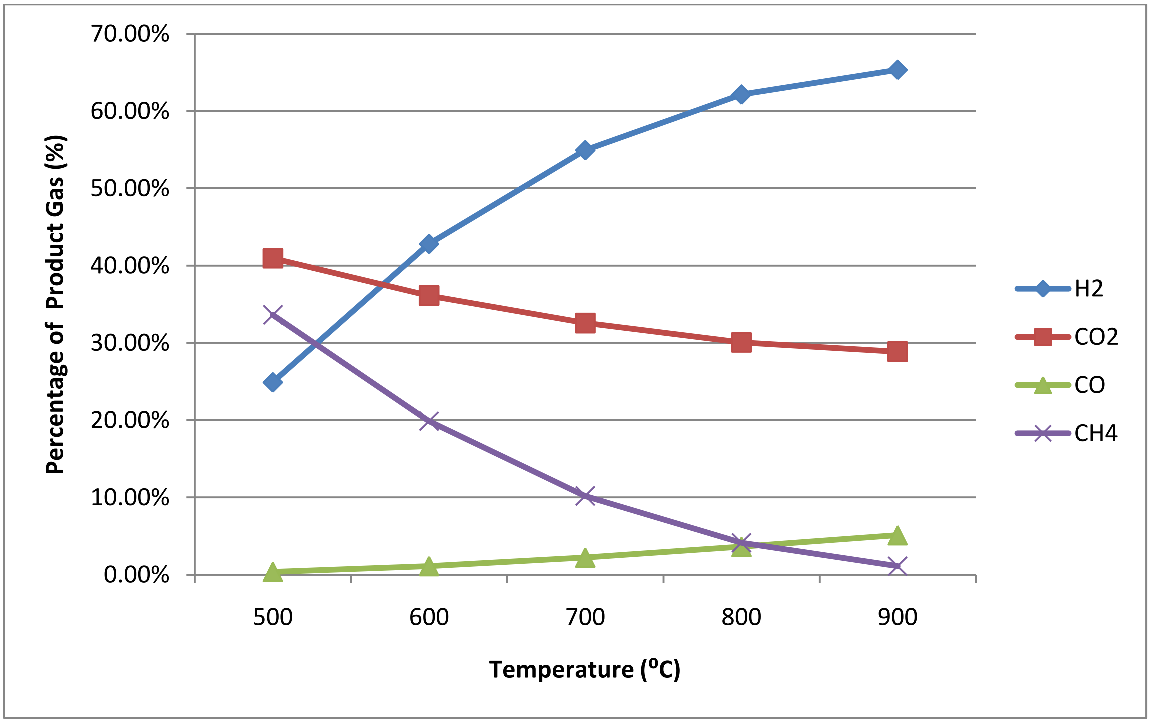

Figure 4.1 Effect of temperature on product gas composition

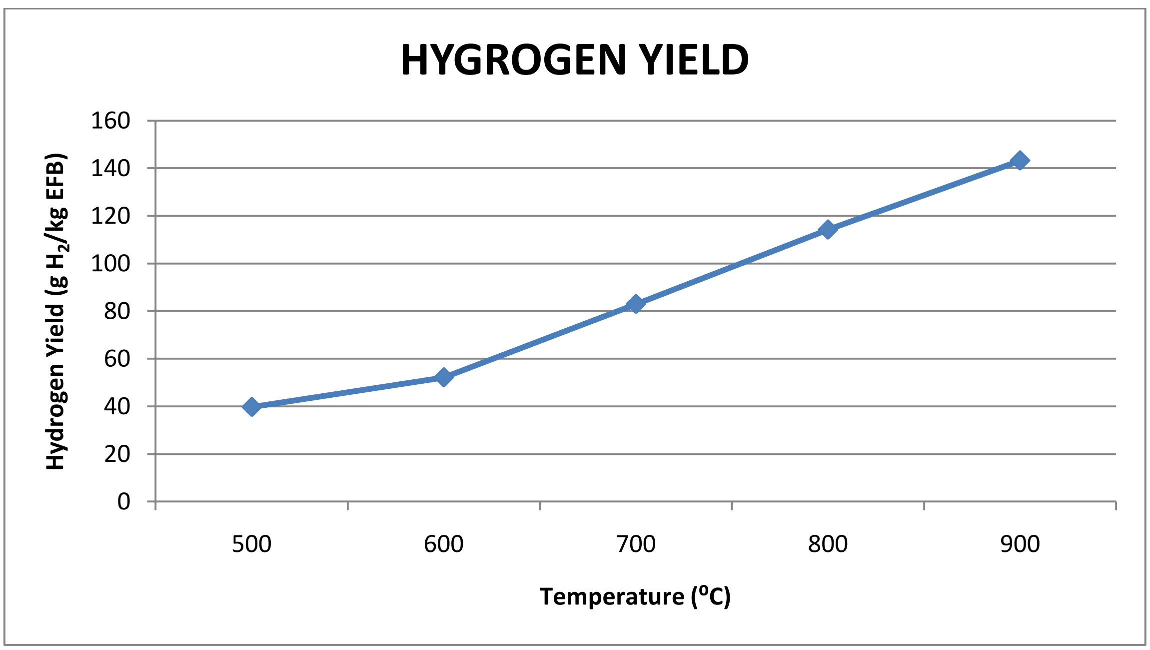

Figure 4.2 Effect of temperature on hydrogen yield

4.2 Effect of Pressure

Figure 4.3 depicts the percentage of product gas produced when the pressure used varied between the range of 250 bars to 450 bars while the temperature was set at 700°C and the concentration of feed was 10%. As claimed by Tushar et al. [31], the effect of pressure on mechanism of supercritical gasification of biomass are very complicated. The density and the ion product of water increase with an increase in pressure while other parameters were kept constant. From Le Chatelier's principle, a reaction that produces more molecules is inhibited at high pressure regions [31]. Thus, the gasification process is generally favored at lower pressures.

The special physical and chemical properties of supercritical water disappear when the pressure is below the critical point, which could inhibit hydrogen production [15]. However, operation at high pressure greatly increases operating costs. As a result, it is a common practice to keep the operating pressure below 300 bar for a supercritical gasification process to balance the effects of pressure on hydrogen yield and operating costs [32]. Figure 4.4 indicates that the hydrogen yield decreased when the pressure used is increased. However, the insignificant changes of hydrogen yield from the result obtained which was less than 15%, shows that pressure is not leading parameters for the process.

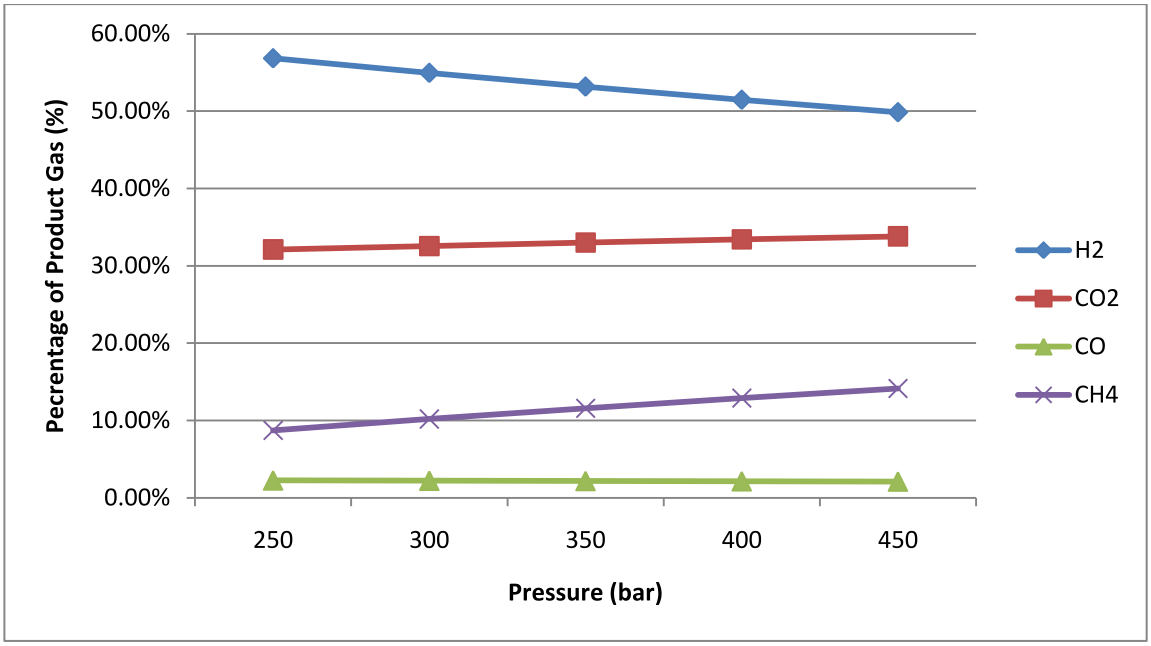

Figure 4.3 Effect of pressure on product gas compositions

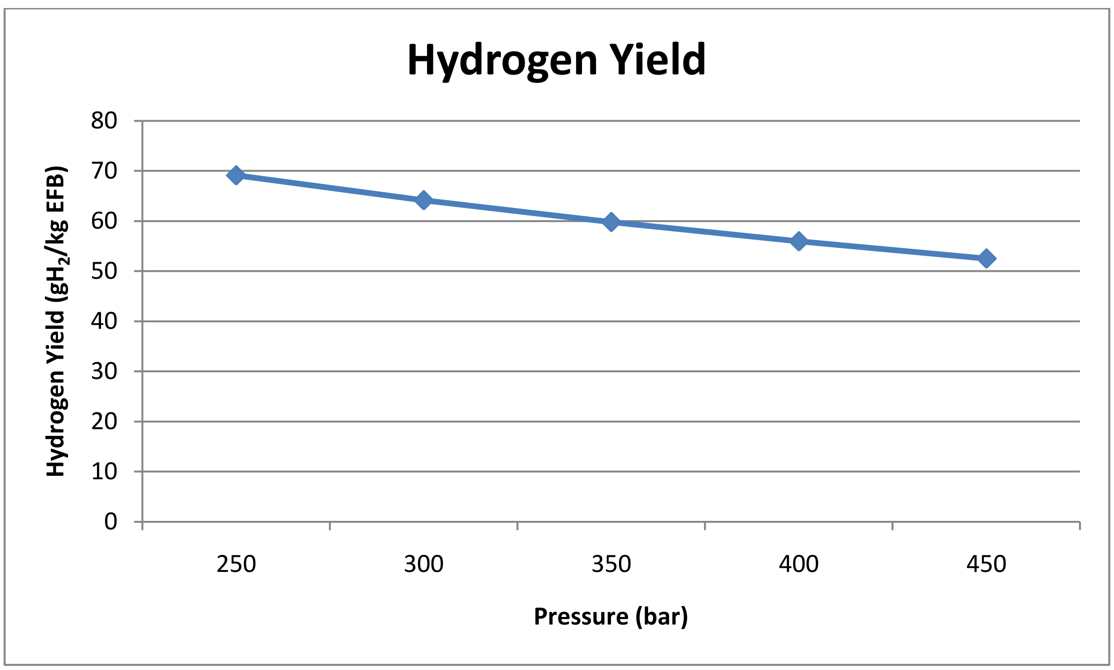

Figure 4.4 Effect of pressure on hydrogen yield

4.3 Effect of Steam to Biomass Ratio

Figure 4.5 shows percentage of product gas composition when the steam to biomass ratio was increased within the range of 2 until 3. The operating temperature was maintained at 700 ^{o}C and the pressure was set at 300 bars. The aim of introducing steam in the gasification was to increase the heating value of the resulting gas owing to increased methane and hydrogen contents [22] .From Figure 4.5, it is observed that the percentage of H_2 produced increased as the steam to biomass ratio increased, whilst other product gases which are CO_2, CO and CH_4 show opposite trend. According to Chen et al. [16], the amount of H_2 increases due to the methane reforming and water gas shift reaction which are highly dependent on the steam feed and based on Le Chatelier's principle, the reactions are pushed forward in the presence of excess steam. As reported by Inayat et al. [18], more EFB and CH_4 are transformed into CO and H_2 as more steam is supplied. Conversely, the percentage of CO keep reducing due to shift forward of equilibrium water gas shift reaction.

As observed from Figure 4.6, the mass of hydrogen yield per 1 kilogram of EFB also increased as steam to biomass ratio increased. From the results, although the amount of H_2 increased with the increasing of steam supplied, beyond a certain limit, it will no longer in favor of the process efficiency because more steam is supplied to the process, more energy is required to generate steam, hence more heat is lost along with the product gas [16].

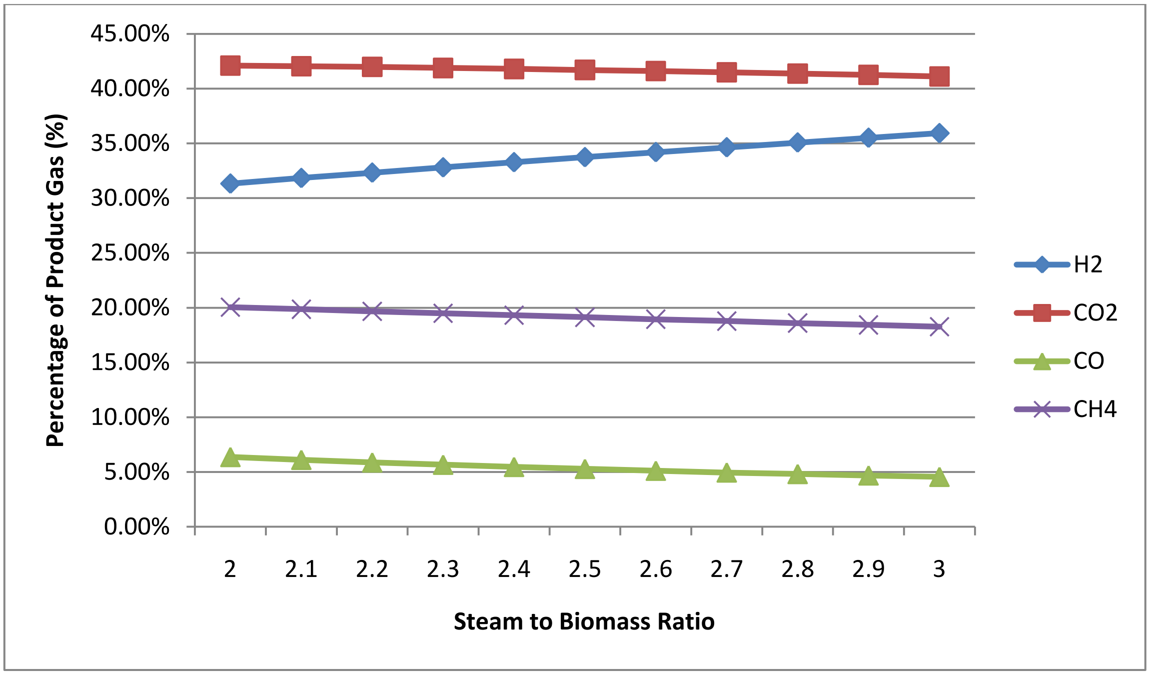

Figure 4.5 Effect of steam to biomass ratio on product gas composition

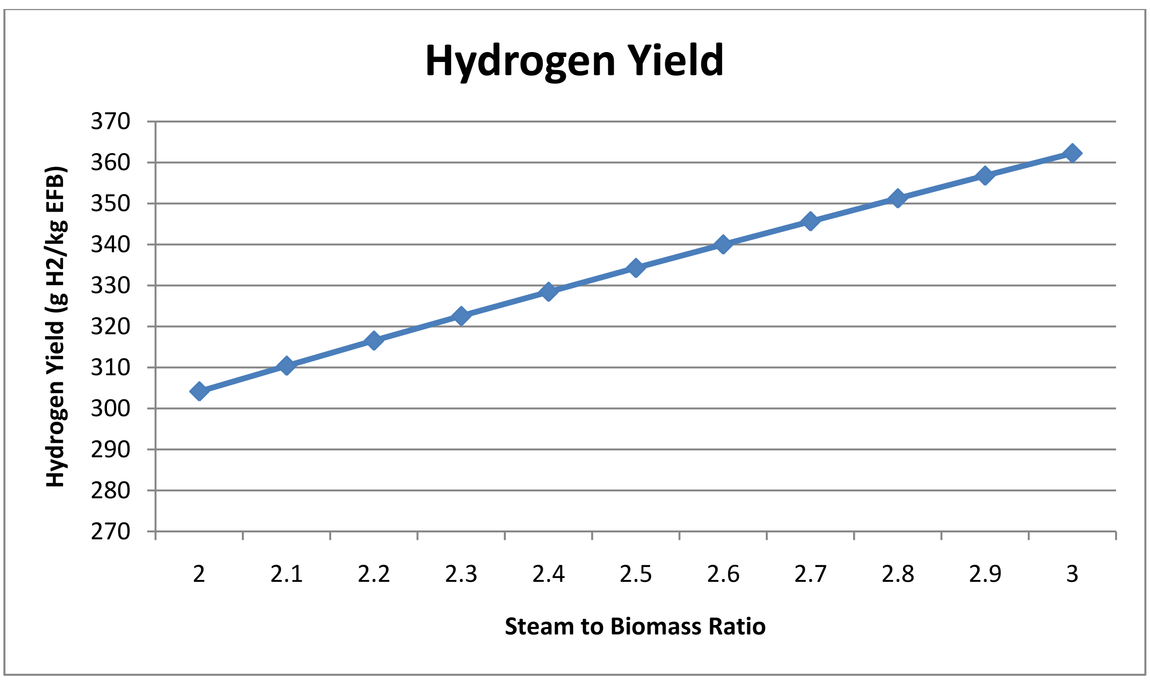

Figure 4.6 Effect of steam to biomass ratio on hydrogen yield

CHAPTER 5

CONCLUSION AND RECOMMENDATION

This work focused on the simulation of hydrogen production using Aspen Hysys. The process of hydrogen production via supercritical gasification technique that uses concentrated solar energy as the source of heat for the process to take place has been simulated. In addition, this project also aimed to perform the parametric studies in order to determine the effect of temperature, pressure and the steam-to-biomass ratio to the amount of hydrogen yield by using the developed simulation. Results obtained from the developed simulation show that increasing in temperature and steam to biomass ratio will promote the amount of hydrogen yield while the changes of pressure does not have significant effect on the amount of hydrogen yield.

Many challenges should be dealt with in the future before applying the concept to industrial scale, such as designing high-efficiency reactor for supercritical gasification with concentrated solar energy and biomass with high dry matter. The usage of solar energy as the external source of energy for heating may reduce the operating cost. However, it is recommended to consider the cost of installation and maintenance of solar system for future studies. In addition, this project is considered to be feasible by taking into account the time constraint and the capability of final year student with the assist from the supervisor and coordinator.

Extensive research should be done in order to yield more hydrogen from palm waste by utilizing the special properties of water at supercritical condition. Besides, it is recommended to perform thermal analysis of available solar collectors and the compatibility with the changes of weather in Malaysia.

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APPENDICES

Temperature

	Temperature (C)				
	500	600	700	800	900
Comp Mole Frac (Carbon)	0.0000	0.0000	0.0000	0.0000	0.0000
Comp Mole Frac (CO)	0.0061	0.0186	0.0366	0.0585	0.0823
Comp Mole Frac (CO2)	0.4890	0.4409	0.3970	0.3584	0.3252
Comp Mole Frac (Methane)	0.3412	0.2447	0.1663	0.1051	0.0591
Comp Mole Frac (H2O)	0.0021	0.0017	0.0013	0.0012	0.0010
Comp Mole Frac (Oxygen)	0.0000	0.0000	0.0000	0.0000	0.0000
Comp Mole Frac (S_Rhombic)	0.0000	0.0000	0.0000	0.0000	0.0000
Comp Mole Frac (Nitrogen)	0.0000	0.0000	0.0000	0.0000	0.0000
Comp Mole Frac (EFB*)	0.0000	0.0000	0.0000	0.0000	0.0000
Comp Mole Frac (Hydrogen)	0.1616	0.2942	0.3988	0.4768	0.5325

Pressure

	Pressure (bar)				
	250	300	350	400	450
Comp Mole Frac (Carbon)	0.0000	0.0000	0.0000	0.0000	0.0000
Comp Mole Frac (CO)	0.0225	0.0222	0.0218	0.0215	0.0211
Comp Mole Frac (CO2)	0.3211	0.3256	0.3299	0.3341	0.3381
Comp Mole Frac (Methane)	0.0873	0.1019	0.1157	0.1289	0.1414
Comp Mole Frac (H2O)	0.0009	0.0009	0.0009	0.0010	0.0010
Comp Mole Frac (Oxygen)	0.0000	0.0000	0.0000	0.0000	0.0000
Comp Mole Frac (S_Rhombic)	0.0000	0.0000	0.0000	0.0000	0.0000
Comp Mole Frac (Nitrogen)	0.0000	0.0000	0.0000	0.0000	0.0000
Comp Mole Frac (EFB*)	0.0000	0.0000	0.0000	0.0000	0.0000
Comp Mole Frac (Hydrogen)	0.5682	0.5494	0.5316	0.5146	0.4984

Steam to Biomass Ratio

	Pressure (bar)										
	2	2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.8	2.9	3
Comp Mole Frac (Carbon)	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Comp Mole Frac (CO)	0.0638	0.0612	0.0588	0.0567	0.0547	0.0529	0.0512	0.0496	0.0482	0.0469	0.0456
Comp Mole Frac (CO2)	0.4209	0.4204	0.4197	0.4188	0.4179	0.4170	0.4159	0.4148	0.4136	0.4124	0.4111
Comp Mole Frac (Methane)	0.2005	0.1986	0.1967	0.1949	0.1931	0.1913	0.1895	0.1878	0.1860	0.1843	0.1826
Comp Mole Frac (H2O)	0.0016	0.0016	0.0016	0.0016	0.0016	0.0015	0.0015	0.0015	0.0015	0.0015	0.0015
Comp Mole Frac (Oxygen)	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Comp Mole Frac (S_Rhombic)	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Comp Mole Frac (Nitrogen)	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Comp Mole Frac (EFB*)	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Comp Mole Frac (Hydrogen)	0.3132	0.3183	0.3232	0.3280	0.3327	0.3373	0.3419	0.3463	0.3507	0.3550	0.3592

Temperature

TEMPERATURE (^{o}C) at 300bar	HYDROGEN YIELDED (kg/h)
500	1.7826
600	3.9682
700	6.4145
800	8.6349
900	9.9744

Pressure

Pressure(bar) at 700 ^{o}C	HYDROGEN YIELDED (kg/h)
250	3.9682
300	52.138
350	82.944
400	114.175
450	143.2

Steam to Biomass Ratio

STEAM TO BIOMASS RATIO	2	2.1	2.2	2.3	2.4	2.5
HYDROGEN YIELDED (kg/h)	3.0418	3.1043	3.1654	3.2254	3.2844	3.3425
STEAM TO BIOMASS RATIO	2.6	2.7	2.8	2.9	3	
HYDROGEN YIELDED (kg/h)	3.3998	3.4564	3.5123	3.5676	3.6223	