

Simulation of SNG Production Through Catalytic Gasification of Biomass

By

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13456

Dissertation submitted in partial fulfillment of

the requirements for the

Bachelor of Engineering (Hons)

(Chemical)

MAY 2014

Universiti Teknologi PETRONAS

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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
Chemical Engineering Programme
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in partial fulfillment of the requirement for the
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(CHEMICAL)

Approved by,

Dr. Abrar Inayat

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

MAY 2014

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 references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

EBTEHAL EISA RAGHEB EISA FARAG

ABSTRACT

With the increasing demand for clean and renewable sources of energy, different kinds of biomass and agricultural wastes have become the focus of research especially in agriculture rich countries like Malaysia, Indonesia, and Thailand. The oil palm is an agro-industrial commodity that is used extensively in the fore mentioned countries to produce edible oil. The residual branches of oil palm fruit tree are a natural and unavoidable by-product of this industry. This paper provides the basic modelling of thermo-chemical energy transformation of residual waste from the oil palm fruit tree to chemical energy using high temperature steam gasification. The final product of this process is pure synthetic natural gas. In the second stage of this project, the operational parameters of the process were investigated and analyzed to develop an operationally optimum model.

The modelling was performed based on data extracted from multiple research papers (stated in text and references), and simulated using AspenTech. HYSYS Version 8.0.

ACKNOWLEDGEMENT

Much gratitude goes out to my supervisor Dr. Abrar Inayat who patiently guided the flow of this project. His patience, help, and encouragement have been essential in the completion of this study.

My profound respect is directed to the scientists who labored over tedious experimental research to produce the data that I have used in the modelling of this study. It is a privilege to be able to envision this study as a small contribution to a long-and growing- line of researches done by devoted scholars who are intent on finding alternatives and solutions to our energy crisis.

The continuous development of this study was guided by the comments and recommendations of examiners donating their time and attention to the subject at hand at different assessment occasions. To all of them, and the ones to come, I say thank you.

Universiti Teknologi PETRONAS as a whole and the chemical engineering department in particular are a source of pride to me personally. The value of the education received in this institution is strongly felt at projects like this these where students get to apply their knowledge and employ the most important skill acquired in a college education which is self-learning. For this skill and all else, I say thank you.

I hope that this simple and small contribution helps in the future of this research.

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ABBREVIATION AND NOMENCLATURE

CSTR: Continuous Flow Stirred Tank Reactor

Ea: Activation Energy of Arrhenius Equation

EFB: Empty Fruit Bunch

HYSYS: Chemical Process Simulator by AspenTech®

NGL: Natural Gas Liquids

PFD: Process Flow Diagram

PFR: Plug Flow Reactor

PFS: Process Flow Sheet

PSA: Pressure Swing Adsorption

SNG: Synthetic Natural Gas

SEDEX: Science and Engineering Design Exhibition

SPEC: Specifications

TEG: Tri-Ethylene Glycol

WG: Water Gas Shift Reaction

CHAPTER 1: INTRODUCTION

1.1 Background of Study

Natural gas is a fossil fuel formed when layers of buried plants and animals are exposed to intense heat and pressure over thousands of years. The energy that the plants originally obtained from the sun is stored in the form of chemical bonds in natural gas. Natural gas is a nonrenewable resource because it cannot be replenished on a human time frame. Natural gas is a hydrocarbon gas mixture consisting primarily of methane, but commonly includes varying amounts of other higher alkanes and even a lesser percentage of carbon dioxide, nitrogen, and hydrogen sulfide. Natural gas is an energy source often used for heating, cooking, and electricity generation. It is also used as fuel for vehicles and as a chemical feedstock in the manufacture of plastics and other commercially important organic chemicals.

Natural gas is a major source of electricity generation through the use of cogeneration, gas turbines and steam turbines. Natural gas burns more cleanly than other hydrocarbon fuels, such as oil and coal, and produces less carbon dioxide per unit of energy released. For an equivalent amount of heat, burning natural gas produces about 30 per cent less carbon dioxide than burning petroleum and about 45 per cent less than burning coal. Combined cycle power generation using natural gas is currently the cleanest available source of power using hydrocarbon fuels, and this technology is widely and increasingly used as natural gas can be obtained at increasingly reasonable costs.

1.2 Problem Statement

The increasing demand for natural gas as a clean power source requires increased production of natural gas, thus which threatens its limited reserve. This rapid depletion of natural gas necessitates developing an artificial alternative which is synthesizing natural gas in an economic and energy-efficient way.

1.3 Objectives

The objective of this research is to investigate the possibility of process optimization through:

- 1- Developing a process flowsheet for SNG production from palm waste using simulation approach.
- 2- Designing a parametric study for higher SNG yield by manipulating operating conditions.

1.4 Scope of Study

In this paper, one set of experimental data has been modeled. The operating parameters were manipulated to achieve maximum process optimization. The scope is limited to the inflow of the biomass sample passing by the various stages of gasification, cleaning and conditioning, Methanation, and ending by fuel upgrading.

The input to the process is an empty fruit branch (EFB) and the output is synthetic natural gas.

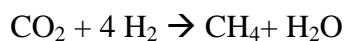
CHAPTER 2: LITERATURE REVIEW

The chemistry of the SNG production depends on the exact composition of the type of biomass used. However, the main equations responsible for the reaction are almost the same. Whichever type of biomass used it must be prepared until it produces carbon monoxide and carbon dioxide where the reaction continues as following:

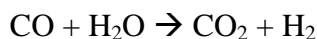
Carbon Monoxide Methanation process:



Carbon Dioxide Methanation Process:



Both reactions are linked by the water gas shift conversion, which is always observed simultaneously whenever active catalysts are used:



A number of observations, reported in Ulmann (1989), indicate that the transformation of carbon dioxide to methane is initiated by a reverse shift conversion reaction with hydrogen to yield carbon monoxide and steam. The carbon monoxide formed then reacts to yield methane.

Both reactions (1) and (2) are strongly exothermic: -206 kJ/mol and -165 kJ/mol, respectively. Also low temperature and high pressure are required to achieve high methane yield.

A study performed by the chemical engineering department of Padova university in Italy with the title of “Synthetic Natural Gas (SNG) from coal and biomass: a survey of existing process technologies, open issues and perspectives” concludes that the “Interest in SNG production is concentrated on the gasification step that may yield high methane content in the raw gas. This is possible, for instance, with Lurgi pressure gasification of coal, especially when gasification pressures of 80-100 bar are applied, as has been successfully tested in recent years (Ulmann, 1989). Lurgi refers

to “The German Chemical and Construction Company” and it signifies the process for making gas from carbonaceous fuel under high pressure.

Methanation processes with little methane in the raw syngas suffer principally from:

1. High exothermic heat release during methanation.
2. Need of handling very large quantities of synthesis gas (four to five volumes of dry synthesis gas yield one volume of methane).
3. High proportion of steam formed during methane synthesis, which limits the directly achievable SNG quality in wet methanation steps.

Four types of methane synthesis process have been developed for commercial operation (Ulmann, 1989). They limit the temperature increase by recycling of reacted gas or steam dilution, or by special techniques such as isothermal reactors or fluidized beds, each with indirect cooling by evaporating water.

A first configuration is the “methane synthesis plant with hot recycle”, in which a two-stage recycle system with a final countercurrent-cooled reactor is used.

This process was originally designed with a recycle quantity such that 500°C is not exceeded at the outlet of the adiabatic reactors. Current systems are available working at maximum temperatures up to 650°C. Inlet temperatures are around 300°C, which is also the operating range of the recycle compressor. An advantage of the hot recycle is that water vapour formed during the methanation reaction is not condensed.

The only commercial-scale coal-to-SNG plant is located in Beulah, North Dakota USA, owned by Dakota Gasification Company. This plant began operating in 1984 and uses 6 million tons of coal per year with an average yearly production of approximately 54 billion standard cubic feet (scf) which is approximately equal to 148 MMSCFD. Synthetic natural gas leaves the plant through a 2-foot-diameter (0.61 m) pipeline, travelling 34 miles south (54.4 Km).

“The heart of the Dakota plant is a building containing 14 gasifiers, which are cylindrical pressure vessels 40 feet high with an inside diameter of 13 feet. Each day

16,000 tons of lignite are fed into the top of the gasifiers. Steam and oxygen are fed into the bottom of the coal beds causing intense combustion (2200°F (~1094°C)). Methanation is the next step, which takes place by passing the cleaned gas over a nickel catalyst causing carbon monoxide and most remaining carbon dioxide to react with free hydrogen to form methane. Final cleanup removes traces of carbon monoxide. The gas is then cooled, dried and compressed and enters the pipeline” (www.dakotagas.com).

Today in the United States many SNG plants are planned and some of them are expected to be operational in the decade 2010-2020 (Petrucci, 2009)”.

There are no industrial scale operations to produce SNG from palm waste yet. “Through 2001 to 2004, Mitsubishi Heavy Industries, Ltd. (MHI) demonstrated once-through operation of woody biomass gasification to methanol synthesis process with a daily biomass throughput of 2 tons. MHI is continuously promoting the development of practically applicable gasification technologies, adaptability to various kinds of biomass such as agricultural waste biomass and woody biomass, gas-purifying techniques for minimizing tar, and the reduction of power consumption” (Mitsubishi Heavy Industries Technical Review Vol. 48 No. 3 September 2011)

Although not yet applied, The Japanese Company MHI confirms the possibility of establishing a large scale plant that deploys what they named as ‘inedible crop parts’ that will produce high yield of power. Although not stated by name in their periodicals, by definition, this applies to palm waste. “The advantages of our technology include the possible use of both woody and herbaceous raw materials such as forest residue, inedible crop parts, and wood waste. A large-scale plant can be established in a small space due to the high yield of heat energy and an increased reaction rate” (Mitsubishi Heavy Industries Technical Review Vol. 48 No. 3 September 2011).

MHI published a diagram of their system used to carry out the series of processes from biomass gasification to gas purifying before supplying the refined syngas to existing chemical plants. The system is shown in the snapshot below.

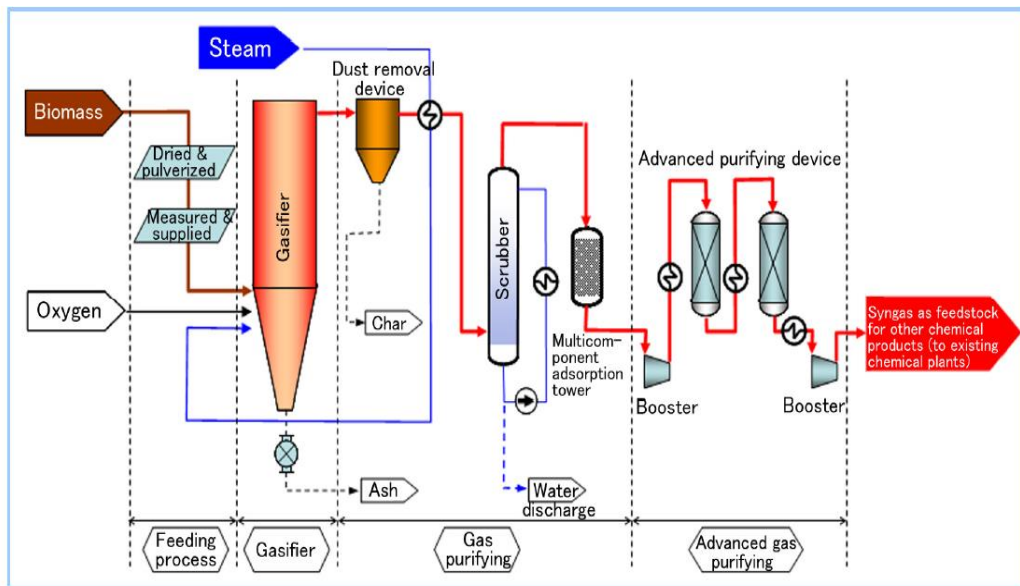


Figure 4 Diagram of the biomass gasification and syngas purifying system.

A diagram of the system used to carry out a series of processes from biomass gasification to gas purifying before supplying the refined syngas to existing chemical plants.

(Picture adapted from MHI Technical Review Vol. 48 No. 3 September 2011)

CHAPTER 3: METHODOLOGY

3.1 Research Methodology

The process was simulated in AspenTech HYSYS V8.0 model. The simulation of the process is preferred to the experimental data collection method because of the weighed advantages of the simulation method in contrast to the limitations imposed by the experimental method in the following aspects:

- 1- The extensive laboratory required safety precautions in the experimental method will represent both cost and time limitations to the yet un-experimented process route.
- 2- Cost effectiveness of the simulation method since any required amount of mass and energy can be provided in the modeling unlike the experimental research method that will require types of equipment and amounts of power that are difficult to provide.
- 3- Time limitation of the experimental method; availability of materials and equipment will contribute negatively to the complexity of the process.
- 4- Environmental impact of the experimental method is yet unevaluated. Handling of resulting exhaust gases adds to the complexity of the process.

3.2 Project Activities

3.2.1 Process Selection

There are numbers of processes in the literature review to be selected. The process that is selected had to be energy efficient and with the highest potential of achieving greater yield. Consequently, steam was selected over oxygen gasification because “oxygen blown gasifiers compared with steam-blown processes have an increased CO₂ content by a factor of 1.5 thus requiring sufficiently larger and costly CO₂ separation processes” (Ref. 4, P.187).

The general process is depicted in the figure below:

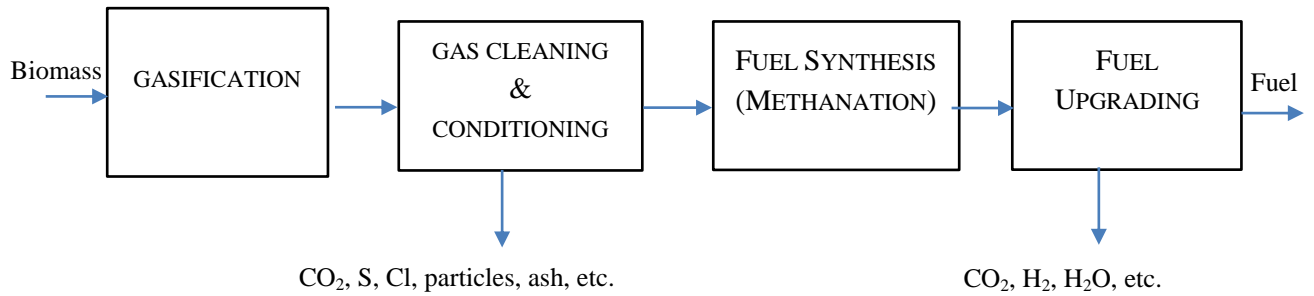


Figure 1: General Process stages for SNG production from Biomass

3.2.2 Process Modelling

The assumptions followed in developing the model for the gasification process (Ref. 9):

- The gasifier is a plug flow reactor under a steady state condition.
- There is no Tar formed throughout the process.
- Reactions proceed at constant volume and are isothermal.
- EFB could be presented by $C_{3.4}H_{4.1}O_{3.3}$

Table 1: List of Process Reactions (Ref. 6, P.4)

No.	Reaction
1	$\text{Biomass} \rightarrow \text{Gas}(\text{H}_2+\text{CO}+\text{CO}_2+\text{C}_n\text{H}_m)+\text{H}_2\text{O}+\text{Tar}+\text{Char}$
2	$\text{Tar} \rightarrow \text{CH}_4+\text{H}_2+\text{H}_2\text{O}+\text{C}_n\text{H}_m$
3	$\text{C}_n\text{H}_m+2n\text{H}_2\text{O} \rightarrow n\text{CO}_2+[2n+(m/2)]\text{H}_2$
4	$\text{C}_n\text{H}_m+n\text{H}_2\text{O} \rightarrow n\text{CO}+[n+(m/2)]\text{H}_2$
5	$\text{CH}_4+\text{H}_2\text{O} \rightarrow \text{CO}+3\text{H}_2$
6	$\text{CO}+\text{H}_2\text{O} \rightarrow \text{CO}_2+\text{H}_2$
7	$\text{C}+\text{H}_2\text{O} \rightarrow \text{CO}+\text{H}_2$
8	$\text{C}+2\text{H}_2\text{O} \rightarrow \text{CO}_2+2\text{H}_2$
9	$\text{C}+\text{CO}_2 \rightarrow 2\text{CO}$

Equations (1) to (8) represent the main reactions that occur during pyrolysis and steam gasification processes. Equation (1) represents the main pyrolysis reaction, while equations (2) to (6) represent secondary reactions occurring during pyrolysis and steam-hydrocarbons reforming. Equations (7) and (8) represent char-steam reactions, and Equation (9) is the Boudard reaction.

3.2.3 Model Design

The process modelling can be done by various ways based on the availability of data.

The main focus during simulation is:

a) Type of reactor used:

For the conversion of the EFB sample to syngas; HYSYS offers many choices of reactors that can be used for different scenarios as discussed below.

Conversion Reactors:

Are easy to use and don't require any information about the reactions kinetics. However, the conversion rates assumed maybe inaccurate or unrealistic. Any data fed to the conversion reactor must be derived from reliable literature and analyzed critically. The use of conversion reactor in the model was limited to the conversion of syngas to Methane, and the conversion rates were derived from experimental data and applied conservatively.

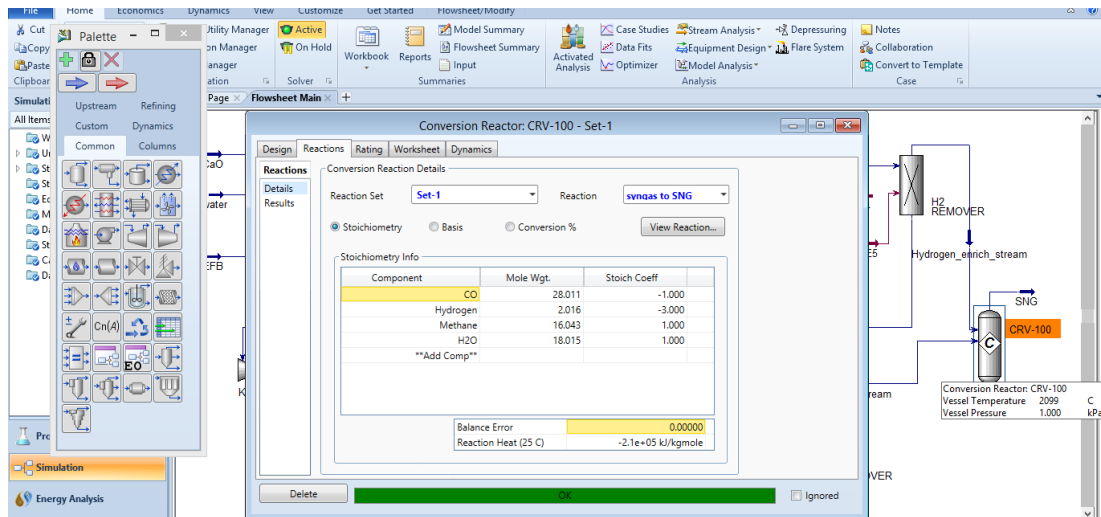


Figure 2: Conversion Reactor Spec Window

Plug Flow Reactor:

Plug Flow Reactors require all the reaction kinetics data. The attached reactions' set to the reactor must be suitable; it cannot be conversion reactions for example. For simplicity the reactions are assumed to be simple rate and attached to the PFR. The specification of the reactor; its volume, length, number of tubes...etc. are all determined by trial and error. The reactor is optimized to achieve the smallest size that will allow the reactions to take place and produce syngas from the fed EFB and steam.

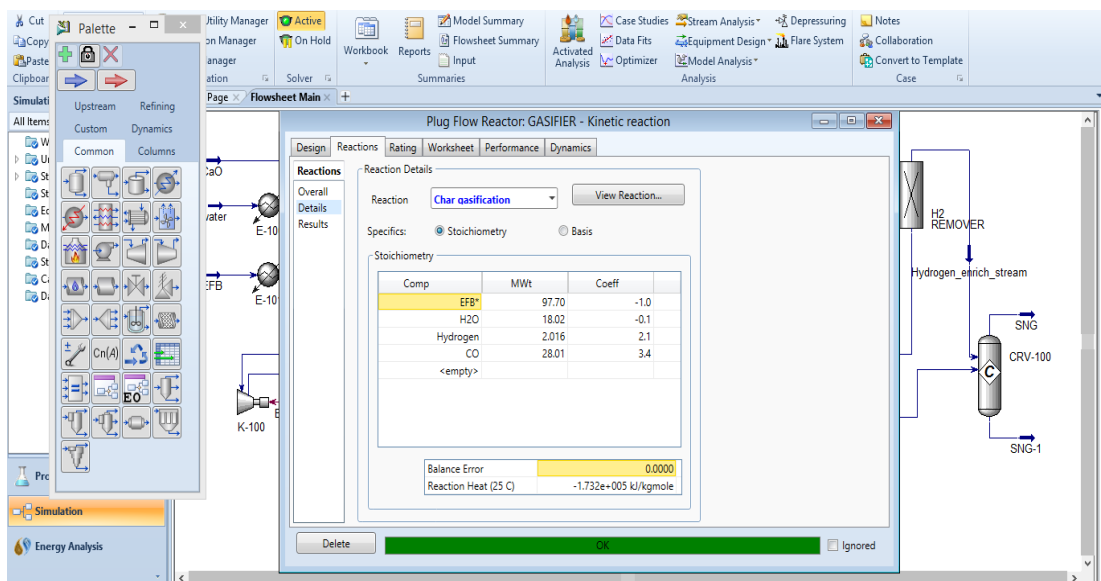


Figure 3: Plug Flow Reactor Spec Window

b) Set of Reactions Used:

There are five forms of reactions that can be entered in HYSYS. To know which ones to use we must know the form of the kinetic data we have

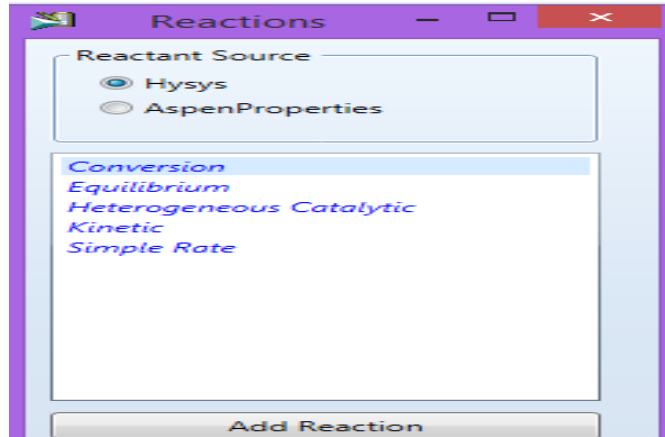
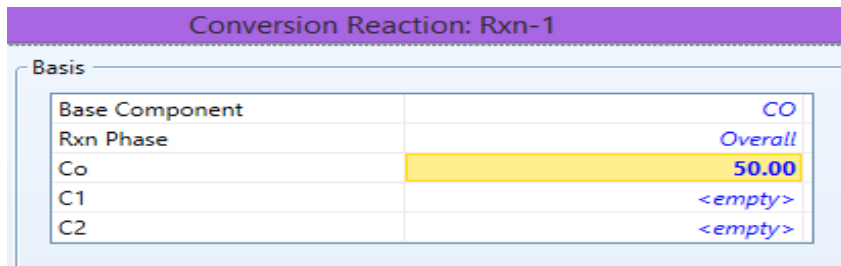
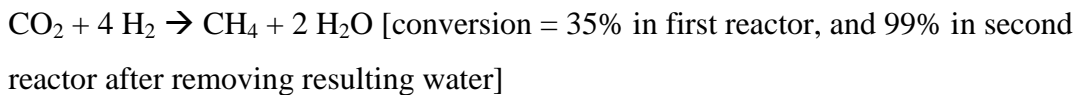
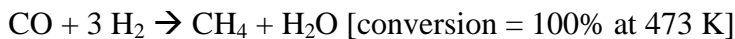


Figure 4: Types of Reactions in HYSYS

Conversion Reaction:

This type of reaction is used in the conversions of syngas to Methane inside the conversion reactors. It requires previous knowledge of the conversion rates from literature. It is essential to ensure that the operating conditions in the simulated model resemble these in the reference literature since conversion rates of reactants rely mainly on the conditions under which the reaction takes place; this means heat exchangers and/or compressors may be used to ensure resemblance of reactants' conditions to literature.



Base Component	Rxn Phase	Conversion
CO	Overall	
Co		50.00
C1		<empty>
C2		<empty>

Figure 5: Conversion Reaction Equation

Simple Rate Reaction:

This type of reactions is used in the conversions of EFB to syngas inside the Plug Flow Reactor (the gasifier). It applies a simple form of reaction rates based on Arrhenius Equation: $r = k * \{f(\text{Basis}) - f'(\text{basis})/K'\}$ and $k = A * \exp(-E/RT) * T^\beta$

The frequency factor (A) and activation energy (E) of every reaction are transferred from reliable experimental literature

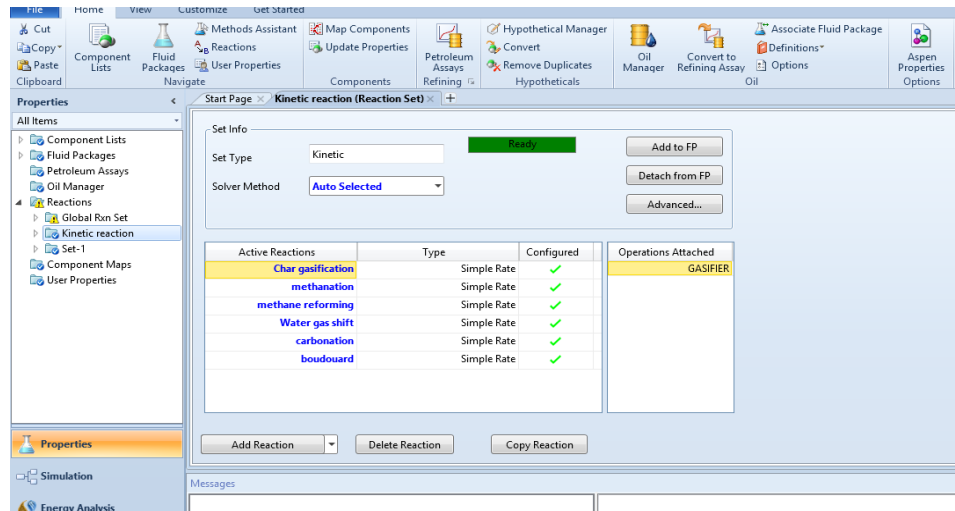


Figure 6: Set of Simple Rate Reactions of PFR

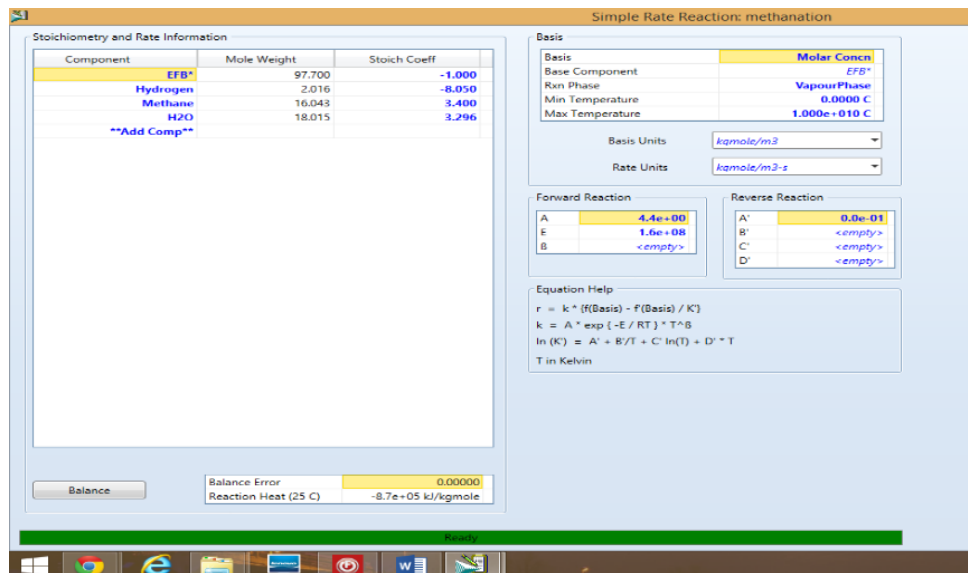


Figure 7: Simple Rate Spec Window

c) Fluid Package selection:

The fluid package used in HYSYS was chosen as to be capable of providing enhanced equations of state for rigorous treatment of hydrocarbon systems, steam correlations for accurate steam property predictions, and activity coefficient models for chemical systems. Thus, Peng-Robinson package was used; Since the components used in this modelling are light hydrocarbons and the simulation has the potential to reach high temperatures and pressures where the system behavior will not be ideal, Peng Robinson fluid package is preferred over the other alternatives. Peng-Robinson fluid package provides VLE calculations and liquid densities of hydrocarbons.

3.2.4 Alternative Process Routes

There were two feasible process routes being investigated. The first process route applied the Pressure Swing Adsorption Method (PSA) where the produced gases from gasification ($H_2 + H_2O + CO + CO_2$) are all separated sequentially. This method depends on applying very high pressure to the gas mixture and then flash it in a column where the lighter gas is separated from the mixture and exits the column at the top. The sequence of separating gases is: Hydrogen, then Water, then Carbon Monoxide in the last column. The Hydrogen and CO streams are then re-mixed in a conversion reactor to produce SNG.

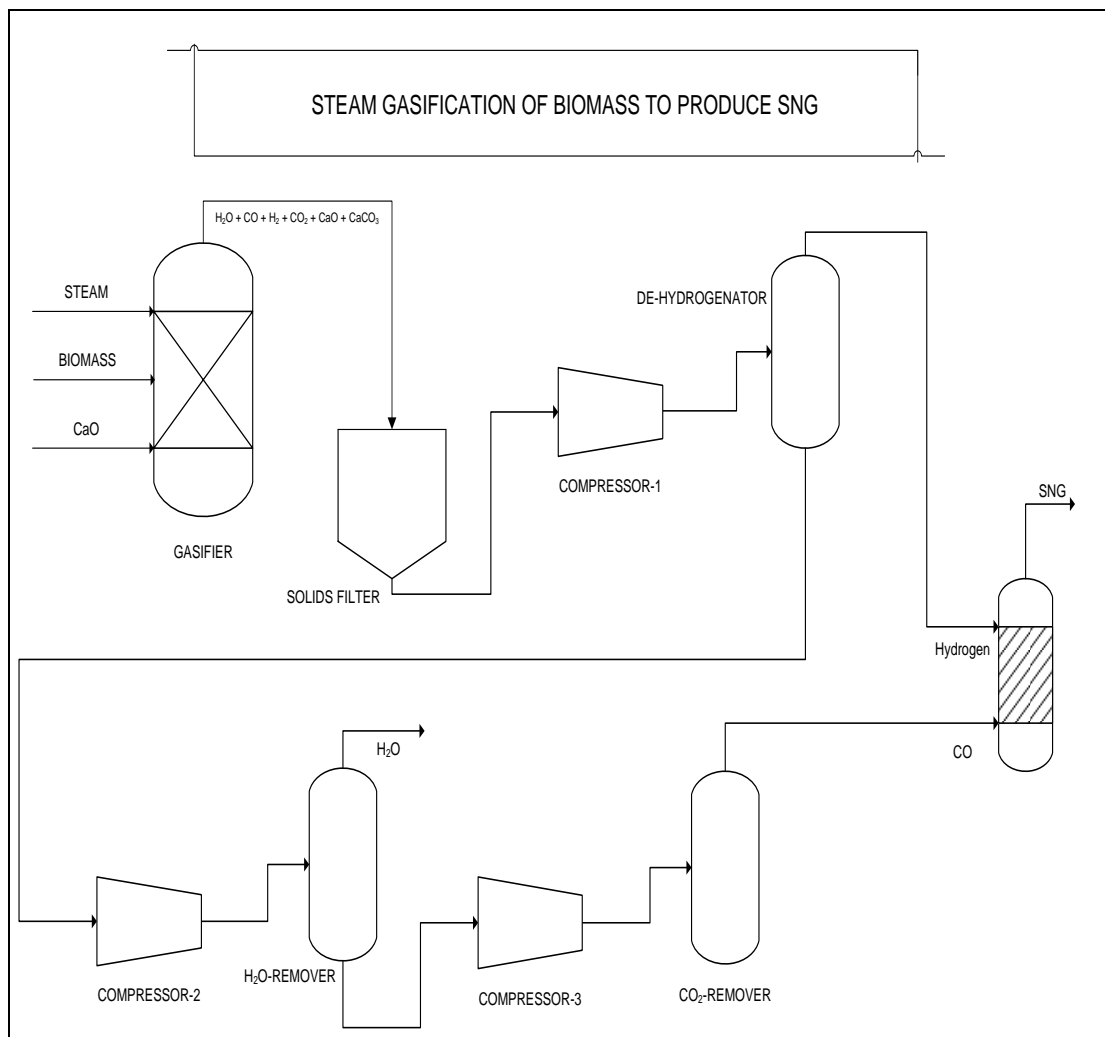


Figure 8: Investigated Process Route 1 (PSA)

The other process route considered was shorter and potentially more cost effective (yet to be decided). The resulting gas mixture from the gasifier is passed through a Tri-Ethylene-Glycol unit (TEG) where the water is removed. The three remaining gases in the mixture are then passed through a conversion reactor where the hydrogen reacts with both CO and CO₂ to produce SNG. The conversion rate of CO₂ doesn't exceed 35% in this reactor due to the occurrence of the preferential CO conversion and the presence of water resulting from the reaction (Ref. 8). Consequently, another TEG unit is added after the first conversion reactor to ensure the purity of gas stream from water and then the mixture is passed through a second conversion reactor where the conversion of CO₂ reaches 99% (Ref. 8).

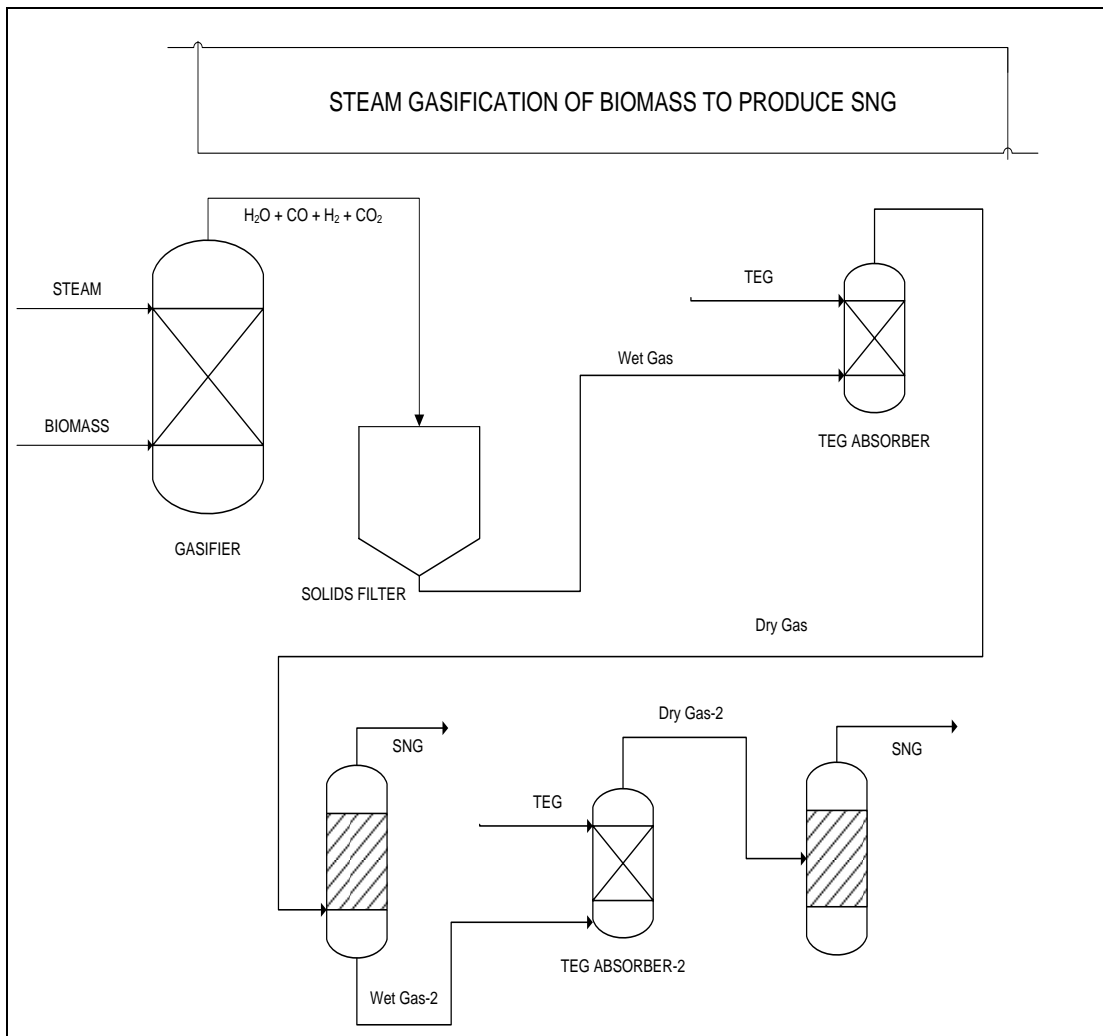


Figure 9: Investigated Process Route 2 (TEG)

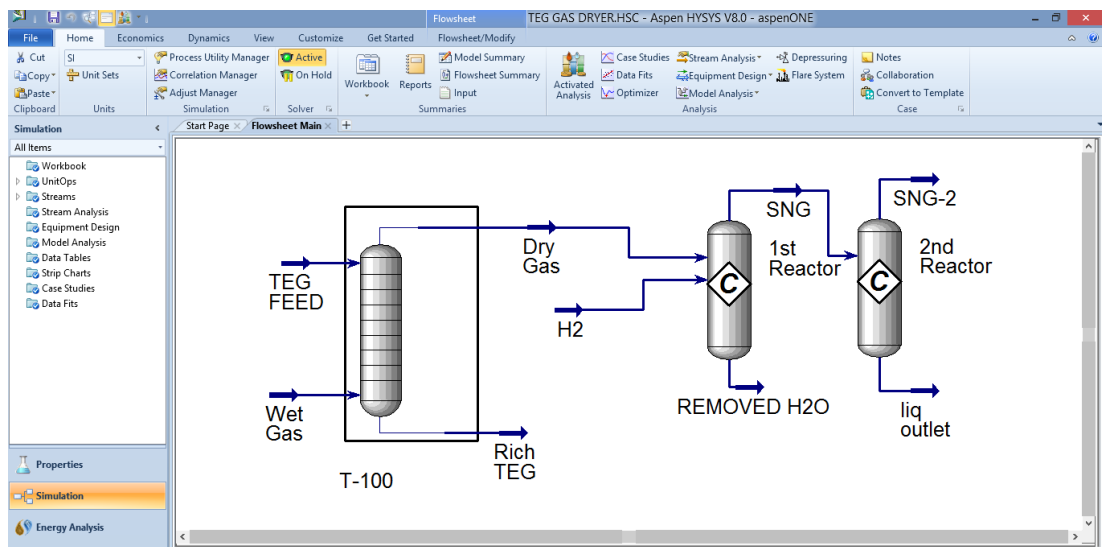


Figure 10: Water Removal via TEG Unit

3.2.5 Analysis of process design and operating parameters

After the construction of the basic skeleton of the process and developing the process flow diagram (FYP I), the second phase of the project started where the operating parameters were manipulated to test their effect on the yield of the product and its purity.

During this stage (FYP II), the HYSYS model was used to compute the change in the process output for every changed parameter. These results were extracted to a Microsoft Excel file where the charts were plotted to represent these changes.

The analysis was done based on the resulting observations until the optimum model was achieved where the operating parameters accomplished the maximum yield with the minimum cost; energy efficient.

3.3 Research Timeline

The project was carried out methodically based on the following timeline:

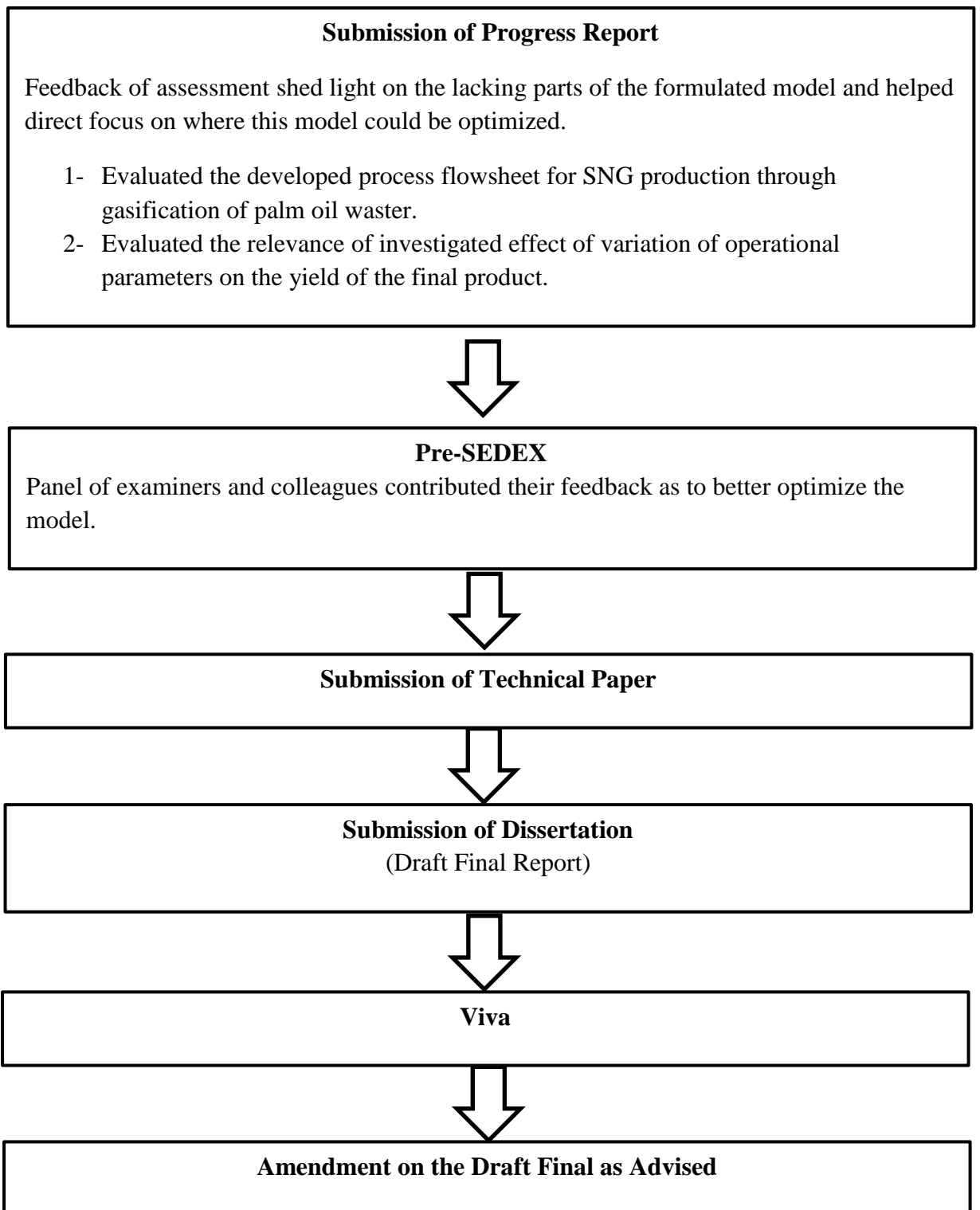
Table 2: GANTT CHART

No	Detail/Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	Study Week
1	Project Work Continues	█	█	█	█	█	█	█								
2	Submission of Progress Report (9 th July)							●								
3	Project Work Continues								█	█	█	█	█			
4	Pre-SEDEX										●					
5	Submission of Draft Final Report											●				
6	Submission of Dissertation (soft bound)												●			
7	Submission of Technical Paper												●			
8	Viva													●		
9	Submission of Project Dissertation (Hard Bound)															●

 Process

 Suggested Milestone

3.4 Key Milestones



3.5 Project Tools

The tools used in developing this project:

Table 3: List of Software used

Software	Purpose
AspenTech HYSYS V8.0	Creating Simulation Model
Microsoft Excel 2013	Graph Plotting and Data Analysis
Microsoft Visio 2007	Plotting Process Flow Diagram

CHAPTER 4: RESULTS AND DISCUSSION

4.1 Data Gathering & Analysis

The obtained results of this project is the development of the alternative process flow diagrams through the steps listed in the methodology (section 3). The second stage of the project was focused on manipulating the operating parameters and analyzing the results obtained.

The biomass sample was named “EFB” and defined as a hypothetical component. The formula of this component was derived from a research paper (Ref. 9) that derived the formula by analyzing the dry mass composition of the sample to calculate the number of moles of each component:

The resulting compound has the formula of: $C_{3.4}H_{4.1}O_{3.3}$ and a molecular weight of 97.7 and an estimated boiling point of 300.3 degree Celsius.

Table 4: Biomass Mass Composition

	Carbon	Hydrogen	Oxygen	Total
Mass Composition (%)	41.760	4.197	54.043	100
Number of Moles (mol)	3.4	4.1	3.3	$C_{3.4}H_{4.1}O_{3.3}$

These values were inserted in the hypothetical component datasheet and HYSYS then “estimates unknown properties”.

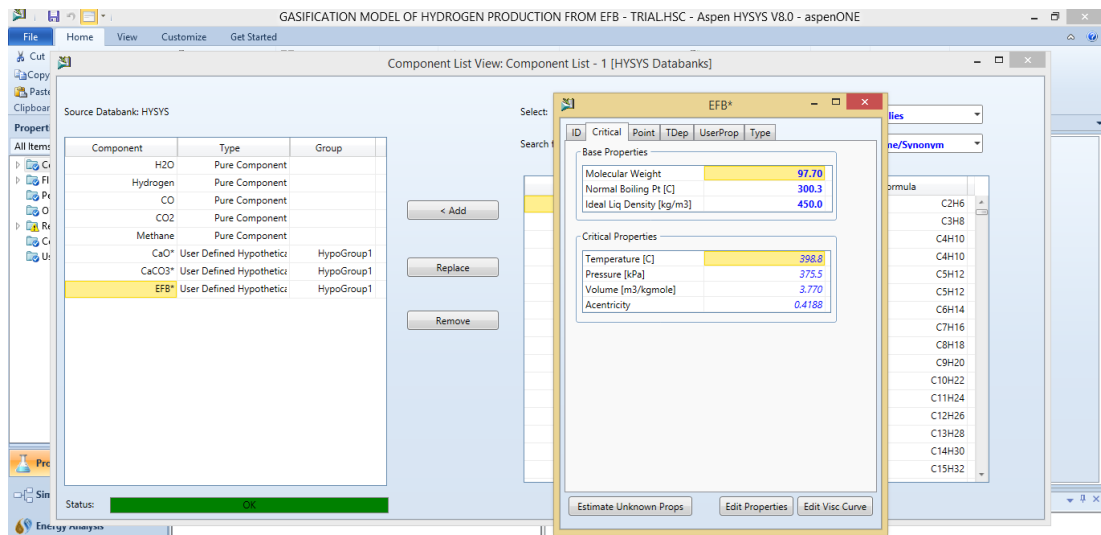


Figure 11: EFB HYSYS properties

The reactions attached to the Plug Flow Reactor are kinetic reactions with the following parameters:

$$r=k*\{f(\text{Basis}) - f^*(\text{Basis})/K'\}$$

$$k=A*\exp\{-E/RT\}*T^B$$

Table 5: Kinetic Reaction Set Parameters

REACTION	Pre-Exponential Factor (A)	Activation Energy (Ea)
Char Gasification	2.0E+05	6.0E+03
Methanation	4.4	1.60E+08
Methane Reforming	3.0E+05	1.50E+04
Water-Gas Shift	1.0E+06	6.40E+03
Carbonation	1.7E-03	2.90E+01
Boudouard	1.2E-01	1.8E+04

Table 6: Balanced Stoichiometric Equations

Reaction	Stoichiometric Equation
Char Gasification	$\text{EFB} + 0.1 \text{ H}_2\text{O} \rightarrow 2.14 \text{ CO} + 3.398 \text{ CO}$
Methanation	$\text{EFB} + 8.05 \text{ H}_2 \rightarrow 3.4 \text{ CH}_4 + 3.296 \text{ H}_2\text{O}$
Methane Reforming	$\text{CH}_4 + \text{H}_2\text{O} \rightarrow \text{CO} + 3 \text{ H}_2$
Water-Gas Shift	$\text{CO} + \text{H}_2\text{O} \rightarrow \text{CO}_2 + \text{H}_2$
Carbonation	$\text{CaO} + \text{CO}_2 \rightarrow \text{CaCO}_3$
Boudouard	$\text{EFB} + \text{CO}_2 \rightarrow 4.4 \text{ CO} + 0.9 \text{ H}_2\text{O} + 1.115 \text{ H}_2$

The bag-house splitter is used in HYSYS for separation of solid particles in the gas stream. The gas stream passes through a filter and so it experiences pressure loss. The pressure drop must be specified in the model. The following values were assumed:

Table 7: Pressure Drop through filter

Obstacle	Pressure Drop
Clean Bag	0.24 kPa
Dirty Bag	2 kPa

PFR dimensions were estimated in order to run the simulation. Conventionally these values were used.

Table 8: PFR Dimensions

Length	5 m
Diameter	0.5 m
Total Volume	0.75 m ³
Number of Tubes	20

The process flow diagram is shown below: The actual modelling was divided into two separate parts where the results were divided into two stages; syngas production from gasification of EFB and syngas conversion to Methane (SNG).

Table 9 shows the results of the first stage. The feed to the gasifier is a mixture of EFB and steam. An additional stream of Calcium Oxide is added to provide a future provision for CO₂ absorption if necessary. However, it's set to zero in this modelling since the CO₂ is assumed to be a part of the syngas that is later converted to SNG by Methanation in presence of Ni-Zr-Sm catalyst.

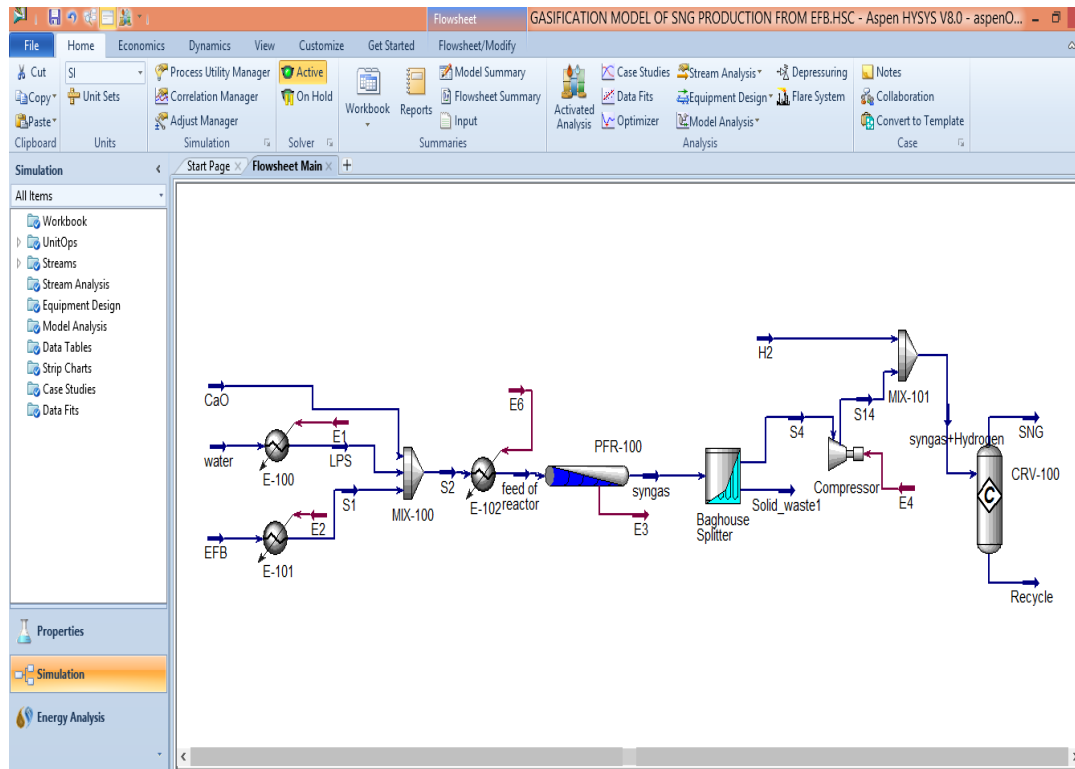


Figure 12: Basic Process Flow Diagram of SNG Production

The current method in producing methane from coal or biomass requires two reactors, the first reactor is where the gasification takes place and the syngas is produced; a mixture of H_2 and CO . The methane is formed later in a second reactor where the syngas is converted to methane in an exothermic reaction.

The process will be immensely optimized if these two reactions happen in the same reactor, which is the goal for many proprietary technologies recently. “In fact, the heat released in the syngas-to-methane step is sufficient to sustain the gasification, eliminating the need to fire up the reactions with purified oxygen. It’s perfectly heat balanced.” (Ref. 7, vii).

The feasibility of merging of these two reactors is recommended to be studied in the later stages of this line of research.

4.2 Results and Discussion

4.2.1 Effect of Temperature

The first batch of results obtained from the model are based on the process route that considers CO₂ as part of the syngas and accordingly CaO flow is set to zero since there is no need to remove CO₂. The results tabulated below show the mass flow of syngas exiting the Plug Flow Reactor (Gasifier) as a result of steam gasification of a gas feed of 4 kg/hour of EFB and 12 kg/hour of steam.

Table 9: Flow of syngas from gasification of EFB at different temperatures

In (°C)	Out (°C)	H ₂ O (kg/h)	H ₂ (kg/h)	CO (kg/h)	CO ₂ (kg/h)	CH ₄ (kg/h)	CaO (kg/h)	CaCO ₃ (kg/h)	EFB (kg/h)
500	500	12	0	0	0	0	0	0	4
525	1004	10.059028	0.38561590	0.9938693	4.561486	8.24E-07	0	0	6.47E-14
550	1036	10.059026	0.385616	0.993867	4.561490	7.84E-07	0	0	9.65E-11
575	1069	10.059025	0.385616	0.993865	4.561494	7.46E-07	0	0	1.87E-11
600	1102	10.059023	0.385616	0.993863	4.561497	7.11E-07	0	0	1.93E-09
650	1167	10.059007	0.385620	0.993874	4.561535	6.48E-07	0	0	4.56E-09
700	1233	10.058999	0.385621	0.993876	4.561553	5.93E-07	0	0	1.20E-09
750	1299	10.059015	0.385617	0.993850	4.561517	5.44E-07	0	0	9.16E-11
800	1364	10.059012	0.385618	0.993847	4.561523	5.01E-07	0	0	1.01E-10
850	1429	10.059010	0.385618	0.993843	4.561528	4.64E-07	0	0	1.49E-11
900	1493	10.059008	0.385618	0.993840	4.561534	4.33E-07	0	0	7.94E-12

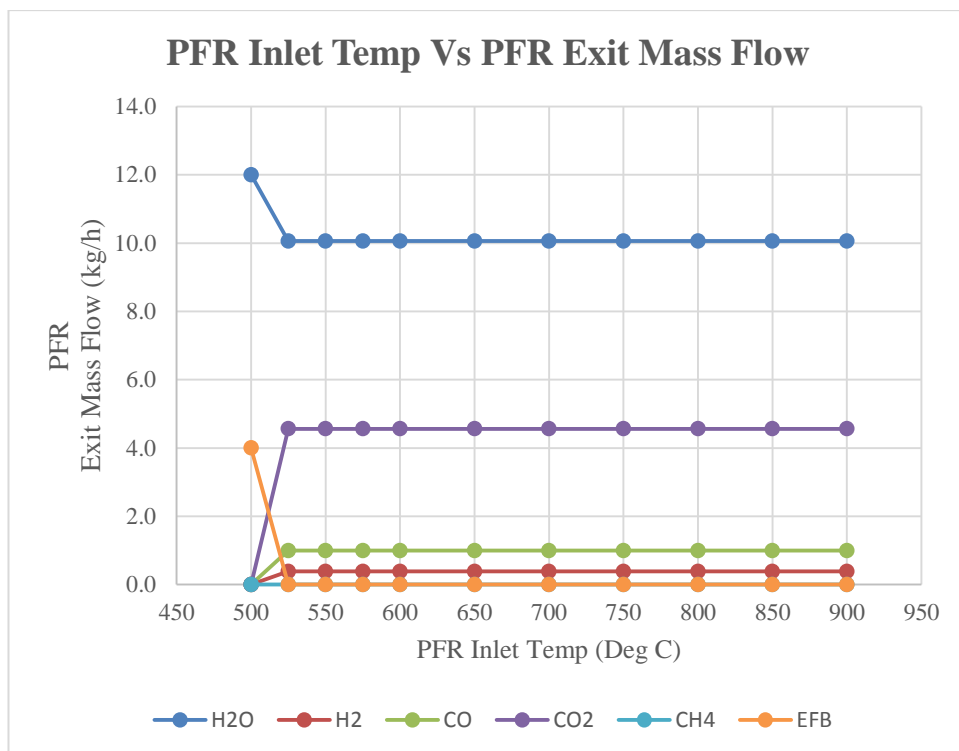


Figure 13: Graph of Temp effect on syngas production

The second stage of the process is the conversion of syngas to Methane. In this stage the syngas was dried in a Tri-Ethylene Glycol absorber to comply with the conditions necessary for maximum conversions of syngas. The conversion rates of CO and CO₂ are then set to 99% and 35% respectively. (The TEG used in drying is under ambient conditions).

It can be concluded that the highest yield of resulting Methane at 525 °C is 828.6265 grams per hour from an EFB feed of 4 kg per hour; this amounts to a yield of 20.716%. The addition of an extra source of Hydrogen strongly enhances the yield of Methane such that an extra of 121 g/h of H₂ amounts to a yield of 28.8%.

Considerable traces of CO and CO₂ are observed in the product, this is attributed to the deficiency of hydrogen required for the Methanation. The hydrogen is depleted and the gases remain unconverted. If an extra source of Hydrogen was to be provided during the Methanation step, the yield would improve significantly.

Table 10 shows the products of the first conversion reactor.

Table 10: Syngas Methanation Results

In (°C)	H ₂ O (kg/h)	H ₂ (kg/h)	CO (kg/h)	CO ₂ (kg/h)	CH ₄ (kg/h)	TEG (kg/h)	EFB (kg/h)
500	12	0	0	0	0		4
1004	9.436003723	0	0.560794582	2.960136438	0.828626561	0.103645153	6.47E-14
1036	9.660054225	0	0.560859133	2.960273635	0.828621715	0.106681904	9.65E-11
1069	9.874338397	4.92E-17	0.560921697	2.960402936	0.828615922	0.109582699	1.87E-11
1102	10.07119305	4.92E-17	0.560978828	2.960518806	0.828610000	0.112242148	1.93E-09
1167	10.40753724	0	0.561081716	2.960728871	0.828604376	0.116798979	4.56E-09
1233	10.68292336	0	0.561164087	2.960875728	0.828588841	0.120536467	1.20E-09
1299	10.90016917	0	0.561205097	2.960934973	0.82855896	0.123480036	9.16E-11
1364	11.06732322	0	0.561239179	2.960972451	0.828537394	0.125744828	1.01E-10
1429	11.19776698	0	0.561262314	2.960971533	0.828510262	0.127512568	1.49E-11
1493	11.29770021	4.92E-17	0.561279472	2.960953462	0.828482282	0.128871497	7.94E-12

The graphical representation of the data tabulated in tables 9 and 10 further illustrates the effect of temperature on the SNG production. Figure 14 shows the decrease of produced Methane over the increasing temperature.

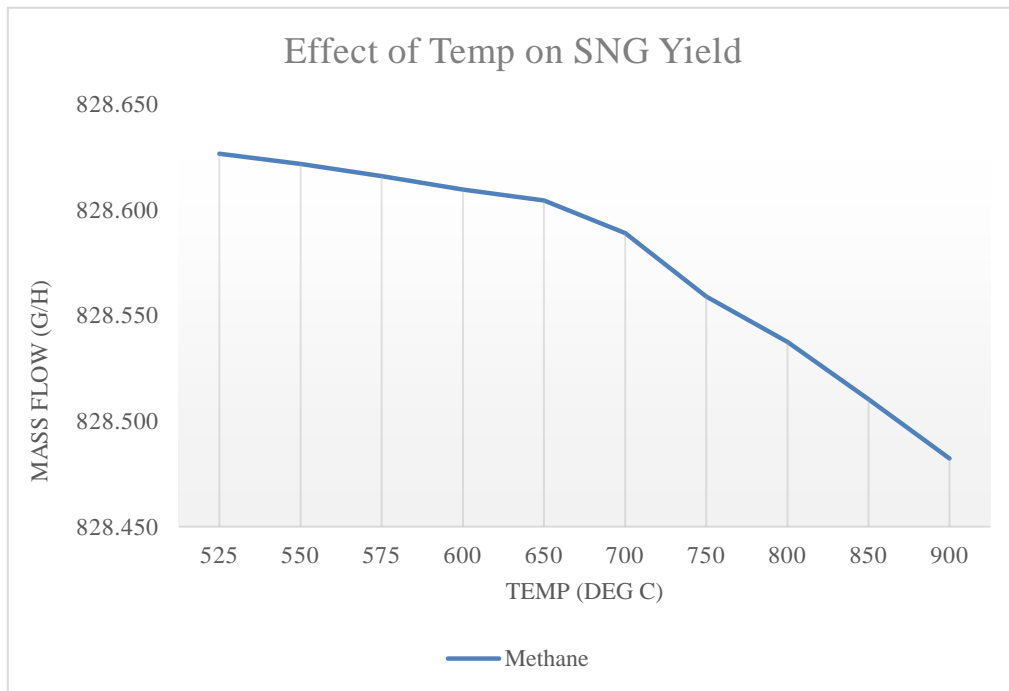


Figure 14: Effect of Temp on SNG Yield

Figure 15 shows the traces of CO and CO₂ remaining in the produced gas. It is clear that the lower the remaining traces, the better the Methane yield, which all happens at 525 °C.

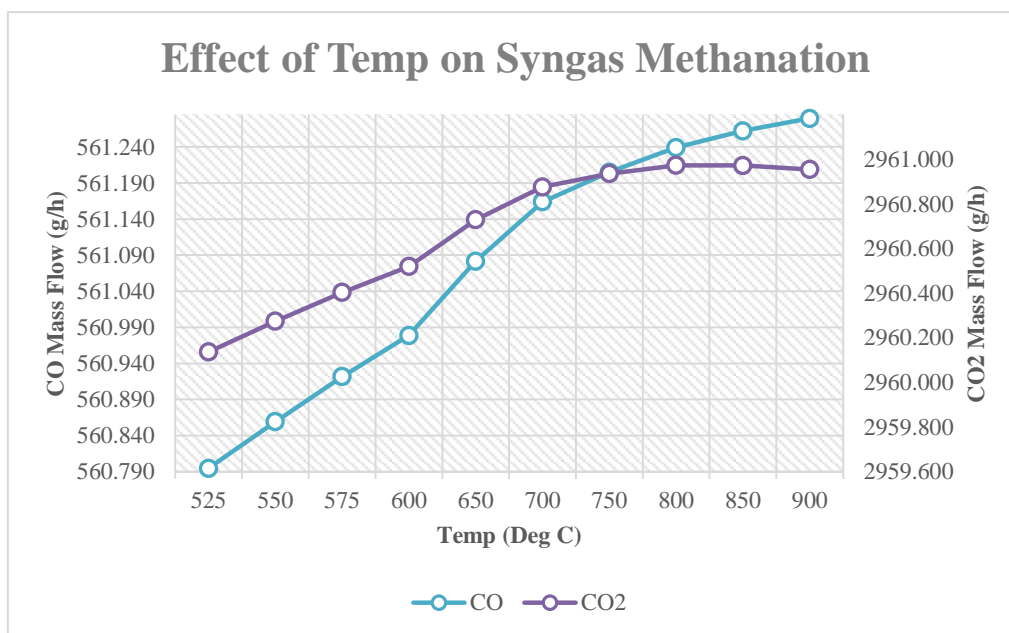


Figure 15: Effect of Temp on syngas Methanation

4.2.2 Effect of Steam Flow Rate

The second operating parameter investigated is the ratio of biomass to steam. The gases produced from the gasification were recorded and tabulated at table 11:

Table 11: Effect of Biomass to Steam Ratio

Feed	Mass Ratio			
	EFB	1	2	3
	H ₂ O	3	3	3
Mole Fraction				
Product	H ₂ O	0.628243832	0.443722175	0.628243835
	Hydrogen	0.215215801	0.305918013	0.215215797
	CO	3.99E-02	1.02E-01	0.03992163
	CO ₂	0.116618688	0.148235208	0.116618689
	Methane	4.95E-08	3.70E-07	4.99E-08
	CaO*	0	0	0
	CaCO ₃ *	0	0	0
	EFB*	5.35E-16	1.66E-12	1.07E-15
		1	1	1

The Inlet mass flow of steam was fixed at 12 kg/h while the EFB is changed from 4 to 8 to 12 Kg/h consecutively. The ratios changing from 1:3 to 2:3 and finally to 1:1.

The effect of the ratio on the produced syngas is depicted in Figure 17 below. It's concluded that the best usable ratio is 2:3 where the mole fractions of H₂+CO+CO₂ are highest and that of water is lowest.

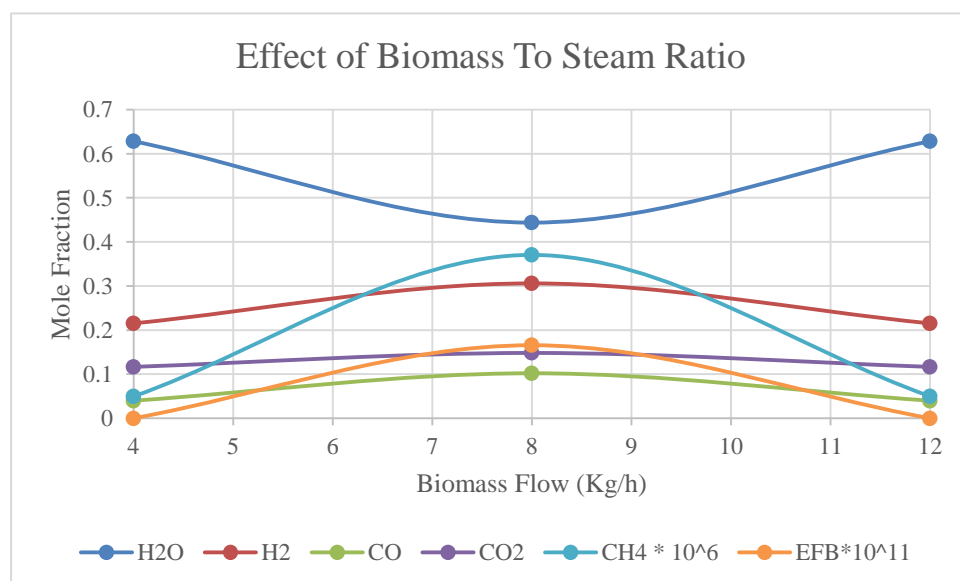


Figure 16: Biomass To Steam Ratio

4.2.3 Effect of Pressure

The graph in figure 6 depicts the results obtained in table 8. It shows that the best results are at gasification pressure of 250 kPa which is equivalent to 2.5 bar.

Table 12: Effect of Gasification Pressure

Pressure (kPa)	250	200	150	101.3
H ₂ O	10.05906	10.05907	10.05901	10.05902
H ₂	0.385614	0.3856111	0.3856215	0.385616
CO	0.993966	0.9939228	0.9939391	0.9938623
CO ₂	4.561402	4.561397	4.56152	4.561498
CH ₄ *10 ⁶	4.30	2.75E+00	1.55E+00	7.11E-01
EFB*10 ¹¹	1.14	5.39E+00	5.85E+00	9.32E-03

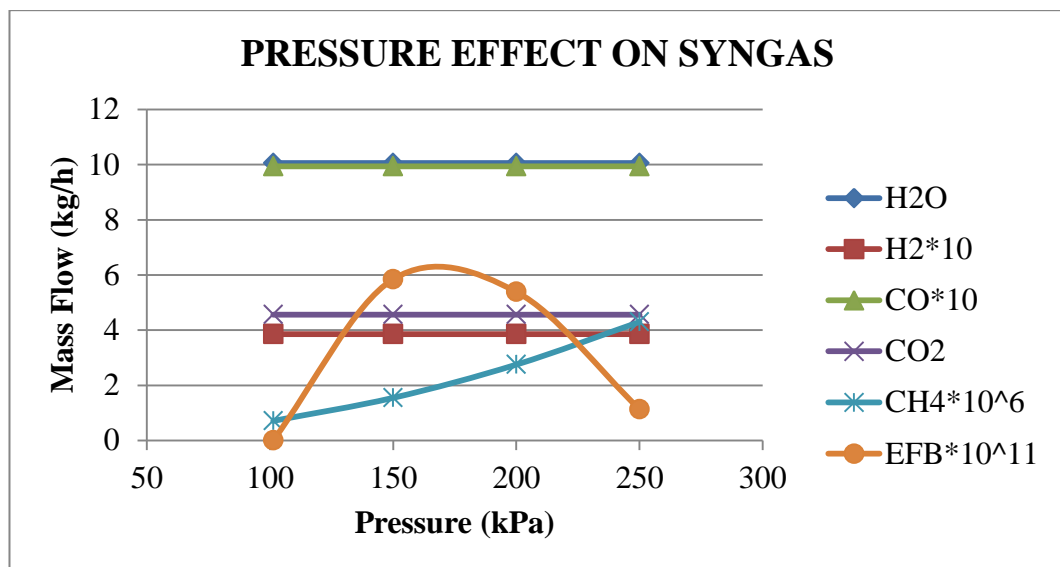


Figure 17: Pressure Effect on Syngas

CHAPTER 5: CONCLUSION AND RECOMMENDATION

5.1 Conclusion

Until renewable energy sources are successfully utilized and economically employed, the world will still depend on petroleum and natural gas as the main energy sources. The efforts of recycling biomass into synthesizing natural gas is a step in the direction of benefiting from the natural environmental cycle in increasing the production of a relatively clean and very efficient energy source that is both in dire need and rapid depletion.

The end goal of this research direction is developing a cost-efficient SNG production process. Thus which can be accomplished by applying optimum operating parameters to achieve maximum yield. The successful implementation of this approach will -in time- lead to a more industrial acceptance of this alternative energy source.

This project presents a simulation model that is based on experimental data for producing synthetic natural gas from steam gasification of oil palm waste. In addition to designing a parametric study to develop an optimized model of this process.

It is concluded that the best yield of Methane is produced at 525 degree Celsius under a pressure of 2.5 bar with a biomass to steam mass ratio of 2:3. The use of innovative approaches such as catalysts of Nickel-zirconium-Samarium hugely improves the yield of SNG as well as providing an extra source of Hydrogen during the Methanation step.

5.2 Recommendations

Certain problems arise during the process of conversion of syngas ($\text{CO} + \text{H}_2 + \text{CO}_2$) to synthetic natural gas (CH_4) known as the “Methanation” step. These issues are extracted from experimental literature (Ref. 1) and stated below:

1. High exothermic heat release during methanation.
2. The Large quantities of syngas produced (stoichiometric equations suggest four to five volumes of dry syngas to yield one volume of methane).
3. High proportion of steam formed during methane synthesis, which limits the directly achievable SNG quality in wet methanation steps.

Future optimization efforts should be directed towards recycling the heat produced from the Methanation step to provide the energy required for the gasification, as well as investigating the possibility of merging the two reactors into one so that the biomass gasification and syngas Methanation steps all happen in the same reactor.

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APPENDIX

Table 13: GASIFIER TUBE DIMENSIONS

Total Volume	0.75
Length (m)	5
Diameter (m)	0.437019
Number of Tubes	1
Wall Thickness (m)	5.00E-03
Elevation (m)	0

Table 14: GASIFIER TUBE PACKING

Void Fraction	1
Void Volume (m ³)	0.75

Table 15: COMPONENT RXN RATES IN GASIFIER

Length [m]	H2O [Kgmole/m ³ -s]	H2 [Kgmole/m ³ -s]	CO [Kgmole/m ³ -s]	CO2 [Kgmole/m ³ -s]	Methane [Kgmole/m ³ -s]	EFB [Kgmole/m ³ -s]
0.125	-8.52E-04	1.51E-03	2.81E-04	8.19E-04	3.47E-10	-3.24E-04
0.375	-1.35E-07	1.43E-07	-1.21E-07	1.35E-07	5.66E-13	-3.97E-09
0.625	-1.83E-10	3.70E-10	1.35E-10	1.73E-10	-1.30E-12	-9.02E-11
0.875	-1.62E-10	3.49E-10	1.56E-10	1.52E-10	-1.30E-12	-9.01E-11
1.125	3.85E-11	-3.85E-11	3.85E-11	-3.85E-11	-6.15E-15	-1.01E-15
1.375	-5.90E-11	4.71E-10	6.46E-10	3.75E-11	-1.37E-12	-2.01E-10
1.625	-2.55E-11	2.56E-11	-2.55E-11	2.55E-11	-2.24E-14	-2.26E-15
1.875	9.72E-11	-9.73E-11	9.72E-11	-9.72E-11	9.66E-16	-1.57E-19
2.125	-9.11E-11	1.19E-09	1.78E-09	2.73E-11	-1.08E-11	-5.30E-10
2.375	7.29E-11	-7.29E-11	7.30E-11	-7.29E-11	-1.82E-14	-5.95E-15
2.625	1.17E-10	-1.17E-10	1.17E-10	-1.17E-10	-4.50E-15	-2.73E-19
2.875	-1.45E-10	4.62E-10	1.94E-10	-2.91E-14	-1.44E-10	-1.48E-11
3.125	-5.25E-11	2.39E-10	2.00E-10	5.13E-14	-4.79E-11	-4.47E-11
3.375	2.71E-10	-2.71E-10	2.72E-10	-2.72E-10	-8.18E-14	-5.03E-16
3.625	2.71E-10	-2.71E-10	2.72E-10	-2.72E-10	-8.18E-14	-5.03E-16
3.875	1.81E-10	-1.81E-10	1.81E-10	-1.81E-10	1.34E-15	-1.81E-17
4.125	-1.22E-09	1.91E-09	-4.89E-11	1.17E-09	-1.42E-11	-3.25E-10
4.375	-1.63E-10	3.49E-10	1.55E-10	1.52E-10	-1.32E-12	-9.01E-11
4.625	1.12E-10	-1.12E-10	1.12E-10	-1.12E-10	-3.78E-15	-1.01E-15
4.875	-4.99E-11	1.97E-10	1.34E-10	-1.87E-14	-4.73E-11	-2.56E-11