Simulation Study of Biomass Gasification

by

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Dissertation submitted in partial fulfillment of the requirements for the

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Perak Darul Ridzuan

CERTIFICATION OF APPROVAL

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Approved by,

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(Dr.Lemma Dendena Tufa,)

UNIVERSITY TECHNOLOGY PETRONAS
BANDAR SRI ISKANDAR, PERAK
JANUARY 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 references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

SUKESH A/L SOUNDARA PANDIAN

ABSTRACT

As the demand of fossil fuel grows day by day, the sources begin to deplete as well as it's a non-renewable energy. Thus the need of a competitive renewable energy which can provide as good as fossil fuels keeps growing. In recent times biomass has emerged as a potential long term replacement for energy source instead of fossil fuel. Biomass gasification is one of the potential technologies that can convert biomass into clean and environmental energy. This is because this technology reduces the emission of Carbon Dioxide to the environment and palm kernel is being used as its feedstock due to the fact it produces high amount of hydrogen gas. This research paper is to develop a steady state and dynamic model of biomass gasification system which is located at Block P in University Teknologi PETRONAS. To fulfill this objective, information regarding the operating conditions of the system, and process flow diagram of the system need to be gathered. With using Aspen HYSYS software, a simulation model of biomass gasification is developed in this paper. In this research the temperature and steam to biomass ratio are manipulated to see the effect on gas production in steady state and dynamic model

ACKNOWLEDGMENT

First and foremost, I would like to thank my dad who is in heaven for his blessing and mercy in allowing me to complete this final year project during the last 8 months. I would like to extend my gratitude to Dr. Lemma Dendena Tufa, The Chemical Engineering Department and University Technology Petronas for giving me the opportunity to conduct this final year project. It has been a privilege to be working under Dr.Lemma supervision. Even with his tight schedules as a lecturer and with his high commitment to University Technology Petronas, he is always available in providing support and guidance to me. His advice and moral support gave me strength and confidence in conducting this final year project

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CHAPTER 1: INTRODUCTION

1.1 Background

This project is about understanding the steady state and dynamic behavior of a biomass gasification process. In current world of globalization, fossil fuel continues to dominate as the main source of energy around the globe. Yet it is widely known that heavy dependent of fossil fuel will only speed up the exhaustion of fossil fuel and result in depletion of its resources in years to come. A number of alternative source of energy has been mentioned to reduce the dependency of fossil fuel and the one which seems to be the most likely to succeed is biomass. In a study it is stated that biomass is one of the biggest source of energy in the world, third only to coal, oil and natural gas (D.Thompson, 2008) . Energy harvested from biomass has been long in use since decades ago. During the time of World War II, one of the most reliable biomass energy based system was used largely for transportation and on farm system were wood or biomass gasification (Rajvanshi, 1986). During photosynthesis, biomass absorbs CO_2 from the atmosphere and the CO_2 is later returned to the environment through the combustion process in the gasification. Due to this cycle, CO_2 is neutral thus giving it an advantage and an overwhelming choice for replacement of fossil fuel (Works, 2010).

Gasification is the process that converts any organic or fossil fuel based carbon materials in to products of carbon monoxide (CO), hydrogen (H_2) and carbon dioxide (CO_2). This process is done by reacting the material (in this project which is biomass) at a high temperature while the amount of oxygen/air controlled with the combination of steam if required. It is also known that biomass gasification is more efficient than combustion. A method to increase the efficiency is by combining the biomass gasification with advanced power generation system such as gas turbine or fuel cells (W.Doherty, A.Reynolds, & D.Kennedy, 2013).

Modeling and simulation are very useful tools to optimize a biomass gasifier design and its operation such as the startup and shutdown with minimal temporal and financial cost (Ahmed, Ahmad, Yusup, Inayat, & Khan, 2012) . The common mathematical models for biomass gasifier are thermodynamic equilibrium models, kinetics models and multiphase computational fluid dynamics (CFD) models. Due to much complexity in the gasification process, most research work done are focused towards kinetics models and equilibrium models. (Ahmed, Ahmad, Yusup, Inayat, & Khan, 2012)

1.2 Problem Statement

Currently it's very common to come across a steady state behavior study for biomass gasification process meanwhile on the other hand dynamic simulation is difficult to come across. Despite the fact that dynamic control of the process modelling is important but very little work on dynamic simulation on dynamic behavior has been conducted. One of the reason why dynamic behavior is important is because, it is crucial in design the control system of the gasifier. With a proper control system, we can now improve the system of the biomass gasifier thus improving its energy production in which the society can now benefit more from renewable energy source making this a steady alternative to fossil fuel

1.3 Objective

The objectives of this project are:

1. To develop steady state and dynamic behavior model of a pilot scale biomass gasification system
2. To conduct a series of steady state and dynamic test to identify the steady state and dynamic behavior of the process

1.4 Scope of Study

This project will utilize the previous research paper findings to identify the most important factors in developing steady state and dynamic equations of a biomass gasifier. The equations that are obtained will be utilized to conduct a series of test using ASPEN HYSYS to analyze the steady state and dynamic behavior of the system.

CHAPTER 2: LITERATURE REVIEW

2.1 Biomass Gasification History

Early origins of using biomass for energy purposes can be traced back to early 1600s. Below is timeline of the origins of biomass gasification discoveries and experimentation work (Energy)

- In 1609, Jan Baptista Van Helmont, a Belgian chemist and physician, discovered that gas could be produced from heating wood or coal. Following this discovery, several others aided in developing and refining the gasification process:
- 1669: Thomas Shirley performs various experiments with carbonated hydrogen.
- Late 1600s: John Clayton experiments with capturing gas produced from coal.
- 1788: Robert Gardner becomes the first to obtain a patent dealing with gasification.
- 1791: John Barber receives the first patent in which "producer gas" was used to drive an internal combustion engine.
- 1798: Biomass gasification is first conceived when Philippe Lebon led efforts to gasify wood.

From the 1800s onwards is when biomass gasification were begun to be used commercially for both industrial and residential purposes. European based gas producer begun to realize the potential of gas for heating and power generation whereby the raw material used were coal and charcoal. Only in the 1900s where petroleum were more commonly used as fuel but during World War II, there were a shortage in petroleum supply thus industries begun going back to gasification. By 1945 it is widely believed that gas was being used as fuel for trucks, buses and both industrial and agricultural machines (Rajvanshi, 1986)

As expected after some time fossil fuel begun to emerge at a considerable inexpensive price and combining with the fact that they are able to produce more heat and power generation, the dependency and usage of biomass gasification started to decline. Despite the declining usage of biomass gasifier, this technology was included in the strategic emergency plan in Sweden after the 1956 Canal Crisis (Rajvanshi, 1986).

2.2 Theory of Gasification

The production of generator gas (producer gas) called gasification, is partial combustion of solid fuel (biomass) and takes place at temperatures of about 1000^0C. The reactor is called a gasifier. Figure 1 is simple block diagram of a biomass gasifier.

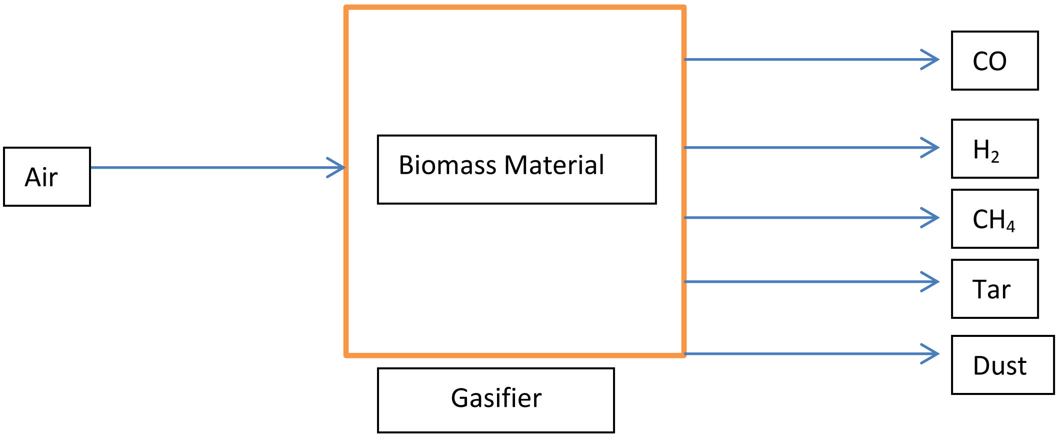


Figure 1: Gasifier Block Diagram

Biomass gasification can be further broken down to 2 types which are "Low Temperature Gasification (700°C to 1000°C)" and "High Temperature Gasification (1200°C to 1600°C). Next, the gasification process can be further broken down to another 5 stages (Labs, 2014). They are:

- Drying of fuel
- Pyrolysis
- Combustion
- Cracking
- Reduction

2.3 THE FIVE PROCESSES OF GASIFICATION

Table 1: Five Process of Gasification

Process	**Temperature (°C)**
Drying	**100-150**
Pyrolysis	**200-500**
Combustion and Cracking	**800-1200**
Reduction	**650-900**

The heat that is provided by the exothermic combustion in the process is absorbed by the drying, pyrolysis and reduction stage. During the drying stage, the moisture content in the solid fuel (biomass material) is evaporated. Pyrolysis is the process where separation of water vapor, organic fluids and other gases from char and solid carbon of the fuel. The combustion stage oxidizes the fuel while the gasification process reduces them to combustible gases in what is an endothermic reaction (Basu, 2006). It may seem that all these stages seem to be overlapping, but it can be assumed each stages takes up a separate phase in the gasifier where different chemical and thermal reactions takes place.

One of the most important stages in the gasification is the drying stage. This is because most biomass material has relatively high moisture content. During drying stage, all or most moisture content in the biomass must be removed before it enters the pyrolysis stage. This is because high content biomass (fuel), and/or poor handling of moisture internally is one of the most common reasons for failure in production of clean gas**.**

Pyrolysis is process of heating the absence of oxygen/air. The fuel is given heat in the absence of oxygen/air. At a temperature above 240°C, biomass begins to breakdown to 3 phases, namely solid, liquid and gas. Initially the water is driven off, than when the temperature inside the gasifier is around 280°C, CO_2, acetic acid and water are given off. The solid remain is called charcoal meanwhile the liquid and gas which was released previously are called as tars. When the temperature is at 280-500°C, the pyrolysis stage produces large quantities of tar and gases that contain CO_2. Besides light tars, some methyl alcohol are also formed. The volatiles in the biomass are than evaporated off as tar gas while the solid remains of fixed carbon to carbon chain are charcoal.

In pyrolysis can be shown in a general reaction:

Biomass + heat = char + gases + vapors or liquid

Combustion is a stage with the only net exothermic process in the gasification process. All heat that drives the drying, pyrolysis and reduction stage comes either directly if else from combustion or indirectly recovered from combustion by heat exchange process in a gasifier. The tar gasses and char from the pyrolysis stage can be used to fuel the combustion stage. (Ventures & Darby, 2011). The reactions in the combustion stage are exothermic and yield a theoretical oxidation temperature of 1200°C. The main reactions in the combustion stage are:

$$\mathbf{C + \tfrac{1}{2}\,O_2 = CO_2 \qquad (-111\ MJ/kg\ mole)}$$

$$\mathbf{H_2 + \tfrac{1}{2}\,O_2 = 2H_2O \qquad (-242\ MJ/kg\ mole)}$$

$$\mathbf{CO + \tfrac{1}{2}\,O_2 = CO \qquad (-283\ MJ/kg\ mole)}$$

Cracking is a process of breaking down large complex molecules in to smaller molecules. Molecules like tar are turned into lighter gases by exposing tar to hear. This is a very important phase in terms of producing clean gas that is compatible for the usage in internal combustion engine. This is because when tar gases condense, it turns into sticky tar and when used in internal combustion engine it will cause fouling of the valves of an engine. Cracking is also crucial in combustion stage because it can ensure complete combustion only if the combustible gases mix thoroughly with oxygen. (Ventures & Darby, 2011)

The reduction stage is about the process of stripping of oxygen atoms from combustible products of the hydrocarbon molecules. This is to ensure the molecules returns to forms that can be burnt again. Reduction is actually the direct reverse of the combustion process. Reduction is the stage of oxygen removal from waste products at high temperature to reproduce combustible gases. Both combustion and reduction are equal but opposite reactions.

In fact, in most burning environments, they are both operating simultaneously, in some form of dynamic equilibrium, with repeated movement back and forth between the two processes (Ventures & Darby, 2011). The following is the reactions that take place during the reduction phase:

Boudouard rxn:	$\mathbf{C + CO_2 = 2CO}$	**(+172 MJ/kg mole)**
Water gas rxn:	$\mathbf{C + H_2O = CO + H_2}$	**(+131 MJ/kg mole)**
CO shift rxn:	$\mathbf{CO + H_2O = CO + H_2}$	**(- 41 MJ/kg mole)**
Methanation rxn:	$\mathbf{C + 2H_2 = CH_4}$	**(- 75 MJ/kg mole)**

2.4 Types of Biomass in Malaysia

Malaysia has what it takes to develop the biomass industry well due to the fact of its rich agro-biomass resources and the ever blooming agriculture industry. It's a fact that Malaysia is one of the largest palm oil producers in the world. Below are some facts about Malaysia's palm oil industry (Ventures & Darby, 2011):

- World palm oil consumption is significantly rising as suggested by current expectation
- Malaysia is the second largest producer of Crude Palm Oil (CPO)
- The main contributor to biomass sources in Malaysia is the palm industry in which projection shows rising capacity, with an estimated 80 million metric tons current annual oil palm biomass generation

Other than empty fruit brunch of oil palm, the following are types of biomass that are present in Malaysia

- Rice Husk
- Palm Kernel shell
- Sugarcane bagasse
- Manure
- Sawdust
- Grass Corps
- Forest Residues
- Municipal solid waste

For this project, the biomass feedstock that is going to be used is the palm kernel shell. This is because, this project is going to simulate the process that is being done in UTP's Block P biomass gasification process. Therefore it is a need to ensure the same kind of feedstock is being used.

2.5 Dynamic Simulation Past Study

For any gasification model, it must be capable of modelling the fundamental process that is taking part in the gasifier. The volatile components in the fuel such as light gases and tar are released by pyrolysis as mentioned before is known as devolatilisation. These volatile components that are released undergo homogeneous reactions. These are more commonly modelled as global reactions and not as detailed reactions involving radicals (Fernando, 2014). For a dynamic model, time must be included in the model. When a dynamic simulation is conducted, the key output variables can be studied.

In a research conducted for the dynamic modelling and simulation study of Texaco gasifier in an IGCC process (Wang, Wang, Guo, Lu, & Gao, 2013) , they mentioned that the simulation results show the dynamic changes of key output variables, including gas temperature, power output and mole percentages of hydrogen, carbon dioxide in the syngas. They studied the dynamic behavior of the gasification model by changing the raw material, using 3 different types of the same raw material

In a researched titled "Experimental study, dynamic modelling, validation and analysis of hydrogen production from biomass pyrolysis/gasification of biomass in a two-stage fixed bed reaction system" (Olaleye, Adedayo, Wu, Nahil, Wang, & Williams, 2014) , the authors came up with experimental results during pyrolysis. The results were obtained at different temperature of the pyrolysis stage. The dynamic model was developed for the biomass pyrolysis/steam reforming process in a two stage fixed bed reactor. The dynamic model does considered the hydrodynamics of the fixed bed reactor, the interfacial mass and energy transfer between the fluid–solid systems and the porous catalyst, and the energy transfer on a kinetic model. It is also mentioned that the model was validated with experimental data and they found that the model is very much in line with the experimental data in predicting the product yields from pyrolysis, hydrogen yield and the temperature profile in steam reforming stage.

The dynamic model can be used to predict the hydrogen production capability of different biomass feedstock (i.e. wood, grass, rice husk, etc.). In the future, such a model can be improved to predict product yields of biomass pyrolysis/steam gasification based on the mass fraction of the biomass' main components (i.e. cellulose, hemicellulose and lignin). The influence of different catalyst particle in the process can also be included.

In most past studies, they are mainly focused on steady-state behavior for gasifier. There has been a lack of research being conducted in terms of dynamic behavior of a gasifier. This issue is well address in a paper titled "Dynamic modeling and simulation of shell gasifier in IGCC" (Sun, Liu, Chen, Zhou, & Su, 2010) when they mentioned that due to lack in dynamic behavior study of biomass gasifier, it halts the commercial usage of IGCC system which has an issue on load changing capability. They believe with more dynamic modelling study of biomass gasifier, this issue can be well address and benefit the industry. An area that governs a lot of interest is the dynamic response of the outlet variables of the gasifier system when the inlet variable (biomass composition) is varied. Among the limited previous studies on the dynamic responses of the gasification process, for a Prenflo coal gasifier, a simplified model was developed to simulate the time varying slag accumulation and flow on the walls, and to evaluate the effects of various operating conditions. The following assumptions are introduced here to describe the dynamic behaviors of the syngas composition and temperature and slag buildup (Sun, Liu, Chen, Zhou, & Su, 2010):

- The devolatilization and all of the phase reactions proceed in a way that is infinitely fast, and the equilibrium of the gas phase can be reached in a very short time compared with the inertial element of the slag layer and maintained throughout the three zones of gasifier.

- The coal conversion rate of original coal carbon stays as a constant of 99.5% in the entire gasifier.

- An equilibrium constant related to the gasification temperature is used to describe the chemical equilibrium for the water/gas shift reaction.

- Nitrogen is assumed to be inert. 90% of the sulfur is assumed to be converted into H2S, and the other 10% is converted into COS.

- 70% of the ash in coal reaches the liquid slag layer at the top of the gasifier, and is then led through the slag tap and subsequently quenched in a water bath.

- The slag model is limited to one dimension, which is independent of height. The melting range of the slag is modeled as a distinct transition temperature. The slag density, thermal conductivity and specific heat of the solid slag layer and liquid slag layer are constants.

- Accumulation of mass and energy occurs in the slag layer. The dynamic behavior of slag layer is caused by the thermal effect, and we neglect the effect associated with the variation of the components in the slag.

- Flow in the liquid slag layer is considered as laminar flow.

Based on these assumptions, they developed the syngas model and the slag model which shows the dynamic behavior of the slag behavior. In their conclusion it is mentioned that the model focuses on the dynamic responses of the slag flow with respect to fundamental variations of the feedstock ratio and what are the dynamic behavior response of the gasification unit in IGCC. With respect to a step change of +1% in the oxygen-to-fuel ratio and a step change of +20% in the steam-to-fuel ratio, the dynamic variation histories of several outlet variables are presented, including the gas temperature, exiting slag mass flow rate, thickness of solid and fluid slag layer, and volume percentages of H_2, CO_2 and CO in syngas. (Sun, Liu, Chen, Zhou, & Su, 2010). They found that the outlet variables are more sensitive to the oxygen to coal ratio than the steam-to-fuel ratio. The internal and external characteristics in the conditions using different coals show similar trends when responding to a same step change in inlet variable. The model was validated by comparing the predicted steady-state results with previous studies under similar working conditions (Sun, Liu, Chen, Zhou, & Su, 2010).

CHAPTER 3: METHODOLOGY

3.1 Research Methodology

This entire project is going to be conduct based on the existing pilot scale biomass plant which is located in University Technology Petronas. The operating conditions and design of the gasifier will be based on the gasifier that is being used here. While the composition of the biomass that will be used in the gasification process will be based from the compositions that are used in this pilot scale plant in University Technology Petronas. Having all these parameters we can now progress to the next phase of the project

By collecting the parameters and conditions from the existing pilot biomass plant, the author now can start working on achieving the first objective of this project which is to develop the steady state and dynamic model of the biomass gasification process. There have been studies done on this biomass plant in University Technology Petronas, thus through literature the author will be able to obtain the steady state model. Once this achieved the author will be attempting to develop the dynamic model of the biomass gasifier. With all data and parameters collected through literature, the author will develop the dynamic model of the biomass gasification process

Once the first objective is achieved, the author will now progress on achieving the second objective which is by using both steady state and dynamic model, a couple of test will be conducted on the models through simulation to study the behavior of the parameters tested in the gasification process. Before the simulation can begin, all calculations regarding the composition and determination of operating parameters will be finalized. The operating conditions of the gasification system includes fuel flow rate, steam to fuel ratio, air to fuel ratio, temperatures of air and steam of the gasifier. Next will be the practice of getting familiar with the usage of Aspen HYSYS. This is conducted to ensure the knowledge and information of the software will be relevant to the project. The outcome the author is looking to study is the dynamic behavior of biomass gasifier when a step change is introduced. For example, when the steam flow rate is increased, what will be the time constant, time delay and non-linearity if there is any. Once the all the input and out variables are determine and finalized, the simulation work will now begin with the guidance of the supervisor or a senior person. As the simulation takes place, further study will be conducted simultaneously to study on the dynamic behavior of biomass gasifier through literature reading. Once the simulation is completed, the results gained will be analyzed to study how the gasifier system behaves (dynamic behavior) when variables are manipulated at the input. This analysis will be tabulated and explanation will be provided for further understanding. The following assumptions were considered in modeling the gasification process:

- Process is isothermal and steady state.
- Biomass de-volatilization is instantaneous in comparison to char gasification.
- Particles are spherical and are not affected in course of the reaction, based on the shrinking core model
- Char comprises only of carbon and ash.
- Char gasification initiates in the bed and ends in the freeboard.
- Liquid modeling is considered rather than solid modeling for biomass due to unavailability of certain parameters.
- The simulation is carried with power-law kinetics.
- The residence time for reactants is sufficiently high to reach chemical equilibrium.

The software that is being used, Aspen HSYSY, uses unit operation blocks, which are models of specific process operations. These blocks are placed on a flow sheet specifying material and energy streams. An extensive built in physical properties is used for the simulation calculations. Aspen HYSYS has the capability to incorporate gasification thermodynamic model into the model. The development of a model in Aspen HYSYS involves the following steps:

1. Stream class specification and property method selection

2. System component specification from previous data

3. Defining the process flow sheet (unit operation blocks, connecting material and energy streams)

4. Specifying feed streams (flow rate, composition and thermodynamic condition)

5. Specifying unit operation blocks (thermodynamic condition and chemical reactions)

3.2 Biomass Feedstock

One of the key information needed for this project is the properties of the feedstock which in this case is palm kernel shell. The table below illustrates the properties of palm kernel shell and the compositation that is to be used in the Aspen HYSYS simulation

Table 2: Composition of Biomass Feedstock

Palm Kernel Shell	
Moisture (%)	9.61
Volatile matter (wt % dry basis)	80.92
Fixed Carbon (wt % dry basis)	14.67
Ash Content	4.31
C (wt % dry basis)	49.74
H (wt % dry basis)	5.68
N (wt % dry basis)	1.02
S (wt % dry basis)	0.27
O (by difference)	43.36
Higher Heating Value	18.46
Calorific Value (MJ/Kg^{-1})	20.40

3.3 Operating Conditions of the Biomass Gasification System

Table 3: Operating Parameters of Biomass Gasification Process in Block P UTP

No	Equipment	Parameters			
		Temperature	Pressure	Flowrate	Capacity
1	Cooling Water Pump	25°C	1 barg	600 L/hr	
2	Reverse Osmosis				
3	Boiler Water Feed Tank				100L
4	Pump		8 barg	15L/hr	
5	Boiler	150°C	6barg	8.2kg/hr	
6	Biomass Feeding Hooper	50-60°C			30L
7	Superheater	400°C	6.9barg	1.96kg/hr	
8	Fluidized Bed Gasifier	700°C	6barg		0.044m3
9	Micro Filter	700°C	6barg		
10	Guard Bed Gasifier	700°C	6barg		0.044m3
11	Gas Polisher Reactor	700°C	6barg		0.044m3
12	RO Feed Pump		6.5barg	2m3/hr	
13	Quenched RO System		7barg	0.5m3/hr	
14	Water Tank				0.5m3
15	Quenched Water Pump		6.5barg	2m3/hr	
16	Steam Desuperheater	300°C	6barg		
17	Water Separator	40-50°C	6arg		
18	Air Booster Pump	40°C	5.5barg	8.9m3/hr	
19	Adsorption Column System	40°C	12barg	5m3/hr	8L

3.4 Process Flow Diagram of Biomass Gasification

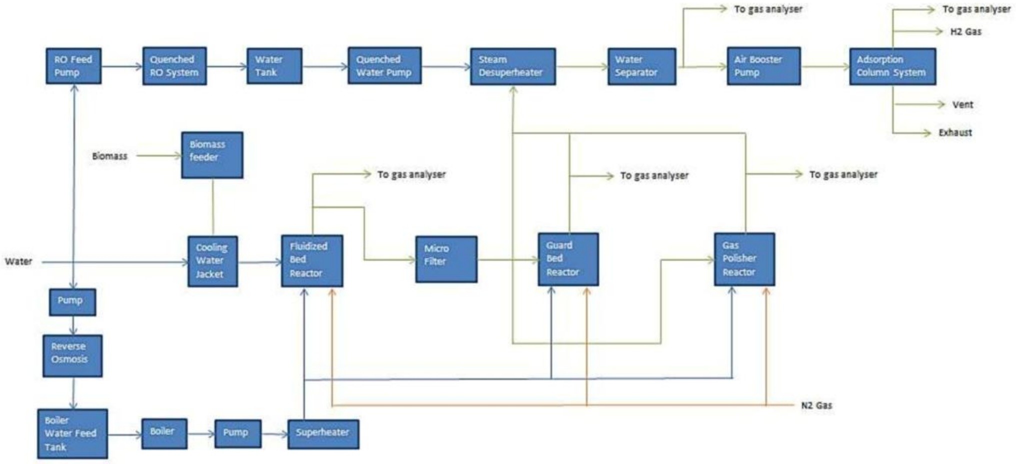


Figure 2: Biomass Gasification Block Diagram

3.5 Biomass Gasification Steady State Simulation in Aspen Hysys

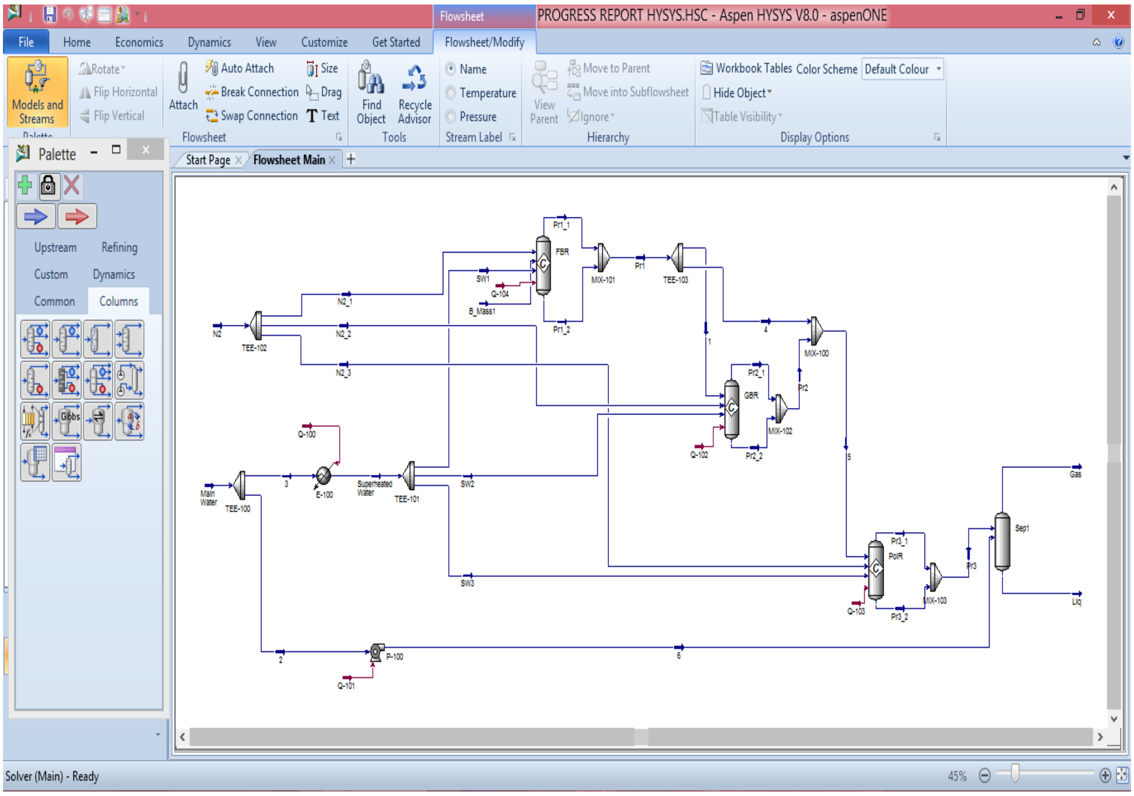


Figure 3: Aspen Hysys Biomass Gasification Steady State Model

3.6 Biomass Gasification Dynamic Simulation Simulation in Aspen Hysys

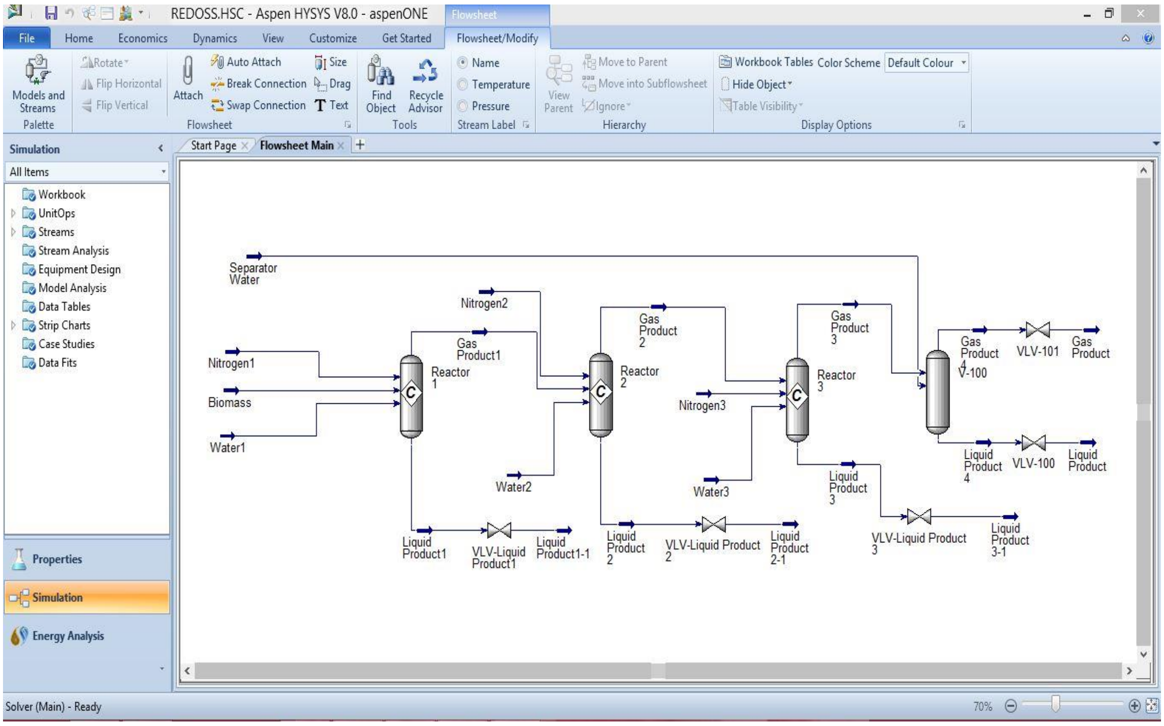


Figure 4: Aspen Hysys Biomass Gasification Dynamic Model

In order to make the steady state model converge in dynamic mode with having been over specified in terms of equation a couple of changes was introduced. First the stream of water going into the reactor was split into 3 different individual streams and the same was done for the nitrogen streams into the reactor. A separate water stream is introduced directly to the separator. A heater is introduce at gas product stream 1 and 2 in order to be able to manipulate the temperature of the reactor in order to conduct the temperature test for the dynamic model

3.7 Project Activities

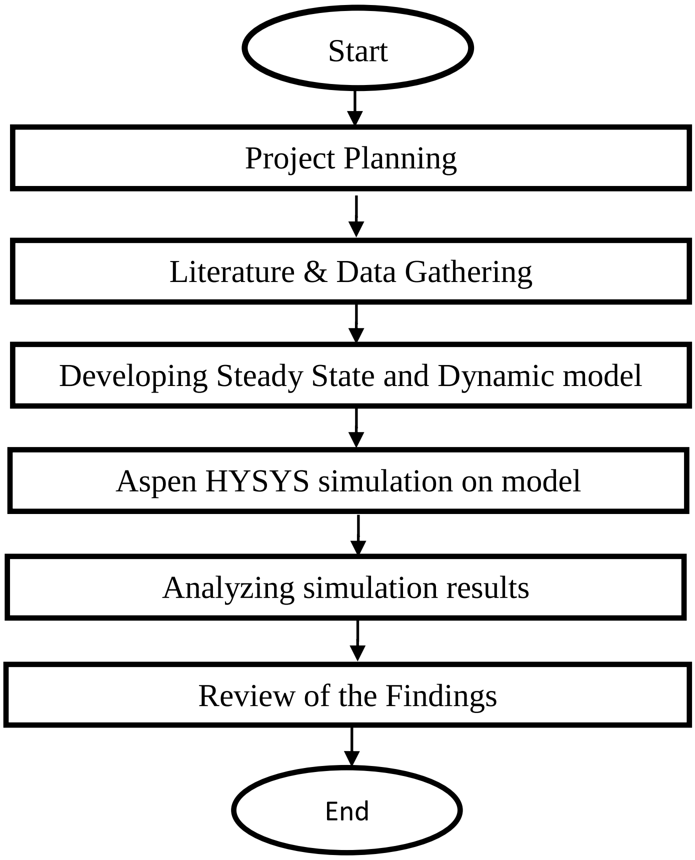


Figure 5: Workflow of project

3.7 Gantt Chart

Table 4: Gantt Chart with Key Milestone For FYP I

No	Detail	Weeks													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Selection of Project	🟥	🟥												
2	Preliminary Research Work			🟥	🟥	🟥	🟥								
3	Submission of Extended Proposal							X							
4	Proposal Defense								X						
5	Development of Steady State Modal									🟥	🟥	🟥	🟥		
6	Completion of Steady State Modal													X	
7	Submission of Interim Draft Report													X	
8	Submission of Interim Report														X

X= Key Milestone

Table 5: Gantt Chart with Key Milestone For FYP II

No	Detail	Weeks													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Development of Dynamic Model	🟥	🟥	🟥	🟥	🟥	🟥								
2	Completion of Dynamic Model							🟥							
2	Submission of Progress Report							🟥 ✕							
3	Project Work Continues with Results Analysation							🟥	🟥	🟥	🟥	🟥	🟥	🟥	
4	Pre-EDX										🟥 ✕				
5	Submission of Draft Report											🟥 ✕			
6	Submission of Dissertation (soft bound)												🟥 ✕		
7	Submission Technical Paper												🟥 ✕		
8	Oral Presentation													🟥 ✕	
9	Submission of Project Dissertation (hard bound)														🟥 ✕

X= Key Milestone

CHAPTER 4: RESULTS AND DISCUSSION

With the project at its mid-point of completion, some data and results are available to be further discussed and understood about this simulation project. A total of four tests will be conducted in this project. Two of the test will be conducted for the steady state system while another two test will be conducted for the dynamic model system. Below is the list of test that will be conducted.

- Test 1: Changing steam to biomass ratio in steady state model and comparing composition of product with experimental results
- Test 2: Changing reactor temperatures in steady state model and comparing composition of product with experimental results
- Test 3: Changing steam to biomass ratio in dynamic model and comparing composition of product with experimental results
- Test 4: Changing reactor temperatures in dynamic model and comparing composition of product with experimental results

In Test one the steam to biomass ratio that was used is 2.5, 2 and 1.5. This is achieved by fixing the steam mass flowrate at 2.7 kg/hr while the biomass mass flowrate was altered from 1.08 kg/hr to 1.35 kg/hr and 1.8 kg/hr. The final stream composition is taken at the end of separator product. Only elements of Hydrogen, Methane, Carbon Dioxide and Carbon Monoxide are compared as it is assumed to be in a dry state and Nitrogen free to match the experimental results. Below are the results of Test 1 tabulated in a form of graph

Test 1: Changing steam to biomass ratio in steady state model and comparing composition of product with experimental results

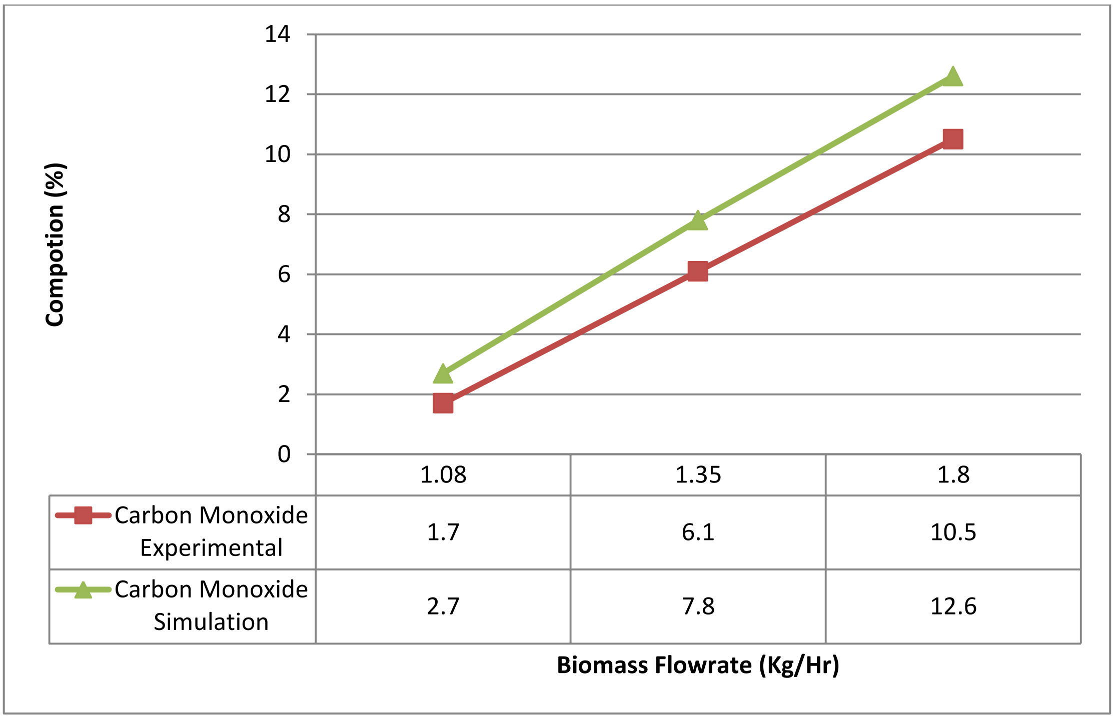


Figure 6: Effect of Steam-Biomass Ratio Variation on Carbon Monoxide Composition

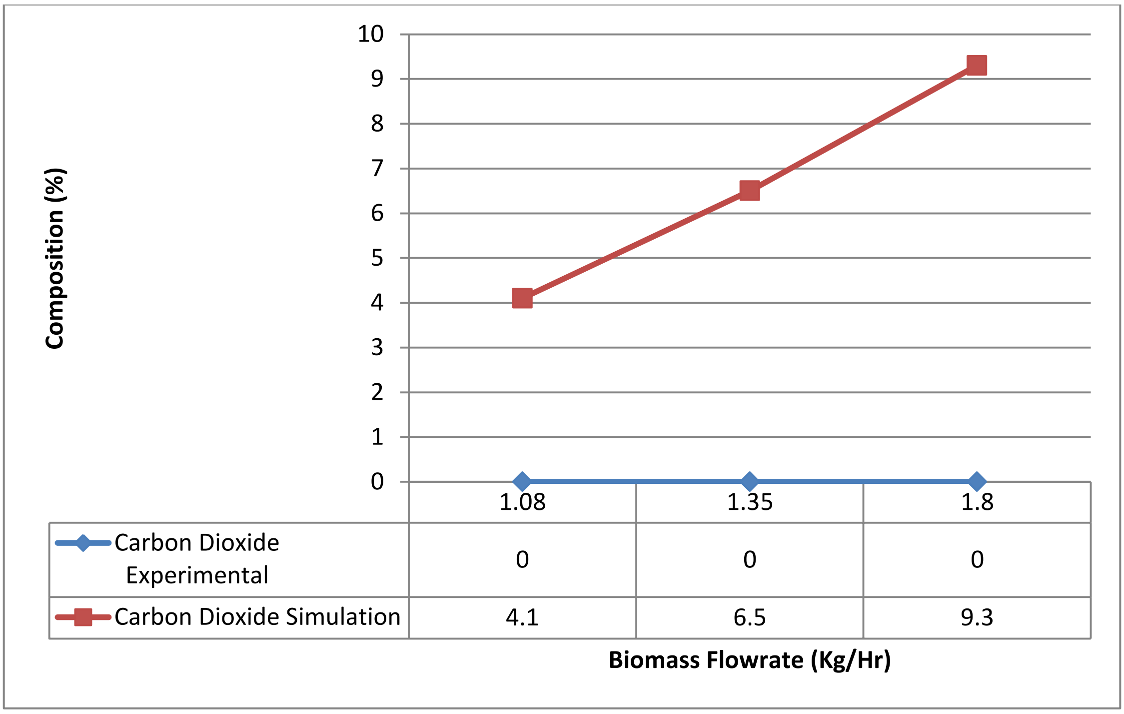


Figure 7: Effect of Steam-Biomass Ratio Variation on Carbon Dioxide Composition

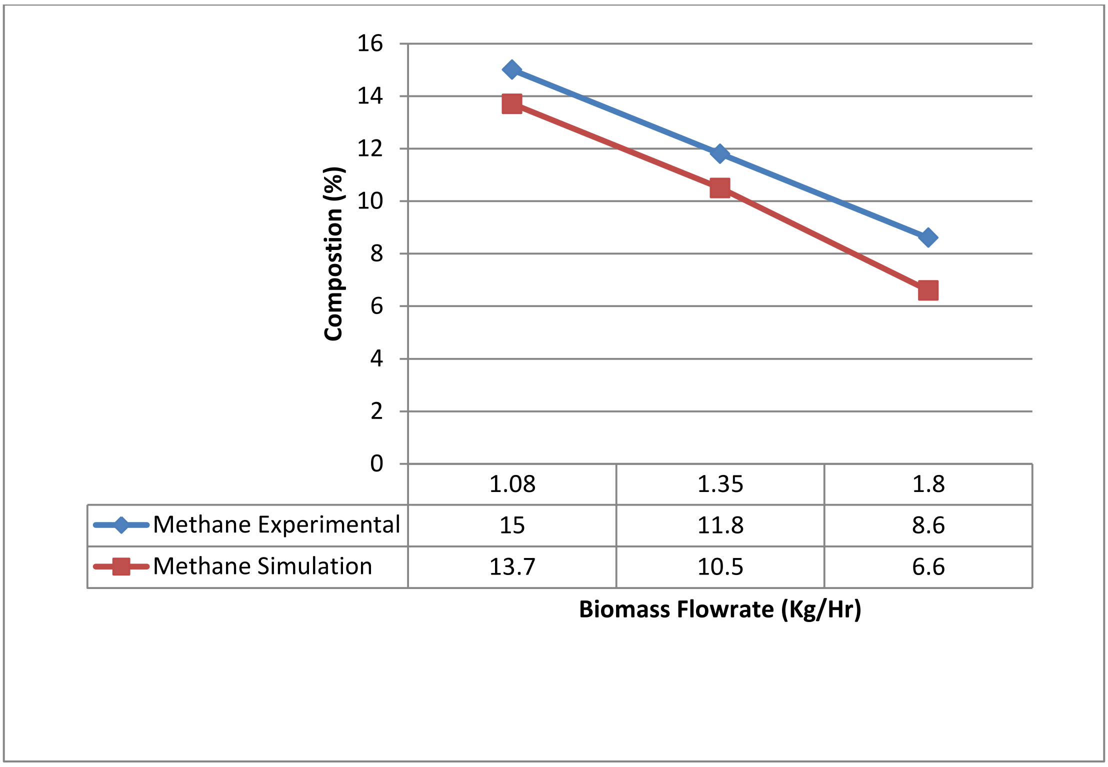


Figure 8: Effect of Steam-Biomass Ratio Variation on Methane Composition

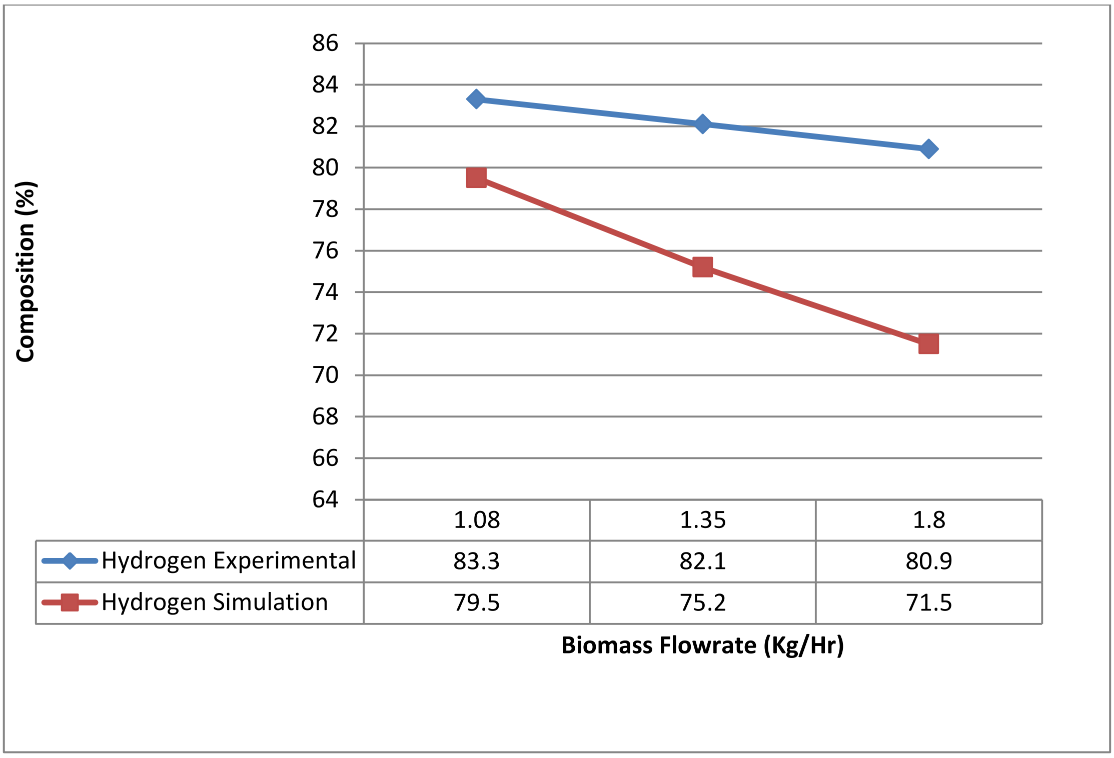
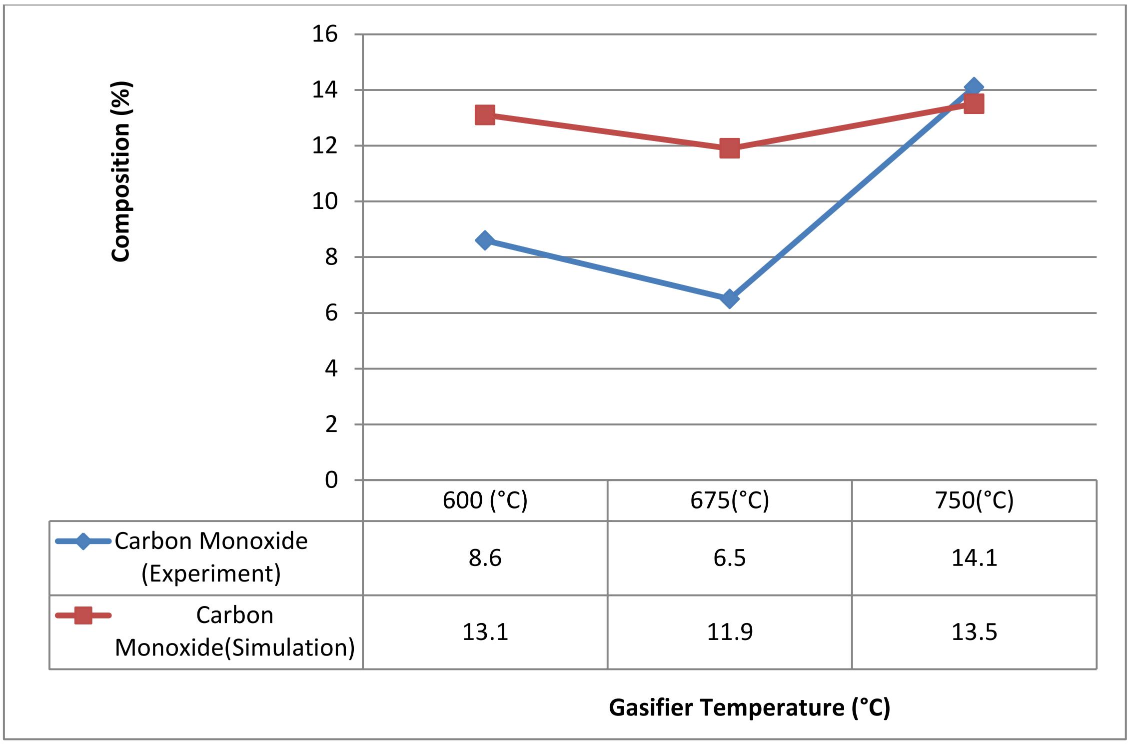


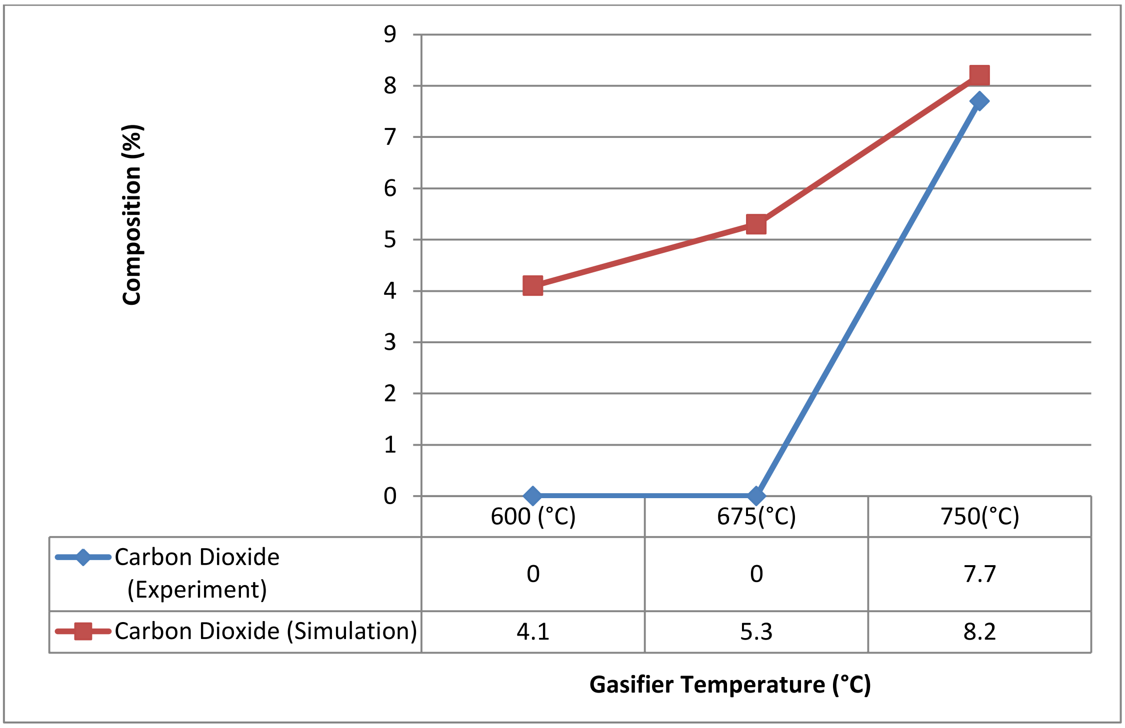
Figure 9: Effect of Steam-Biomass Ratio Variation on Hydrogen Composition

Test 2: Changing reactor temperatures in steady state model and comparing composition of product with experimental results



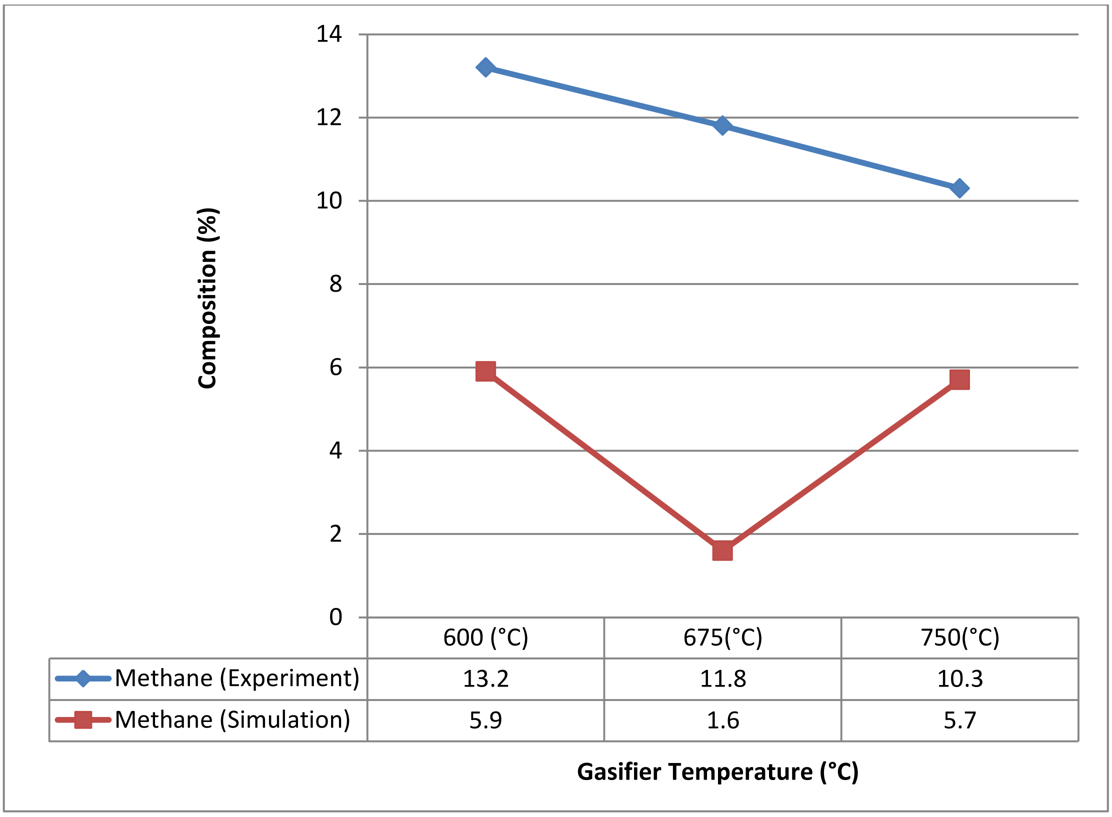
	600 (°C)	675(°C)	750(°C)
Carbon Monoxide (Experiment)	8.6	6.5	14.1
Carbon Monoxide(Simulation)	13.1	11.9	13.5

Figure 10: Effect of Reactor Temperature Variation on Carbon Monoxide Composition



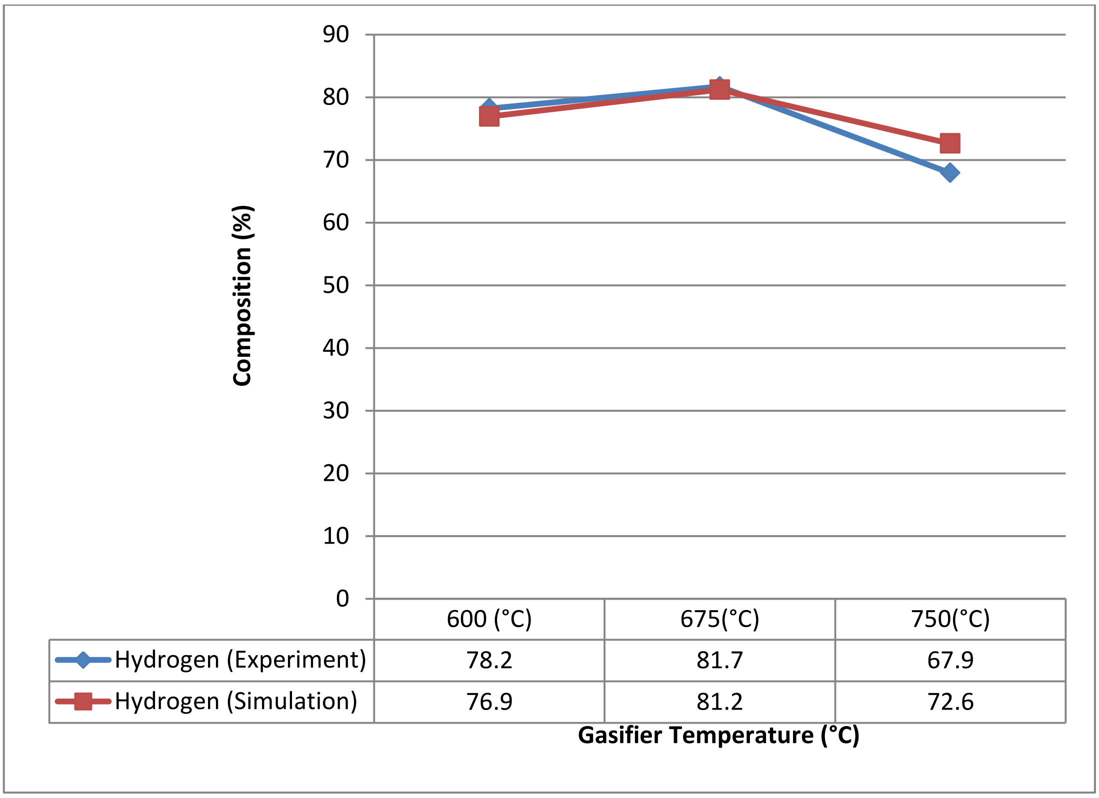
	600 (°C)	675(°C)	750(°C)
Carbon Dioxide (Experiment)	0	0	7.7
Carbon Dioxide (Simulation)	4.1	5.3	8.2

Figure 11: Effect of Reactor Temperature Variation on Carbon Dioxide Composition



	600 (°C)	675(°C)	750(°C)
Methane (Experiment)	13.2	11.8	10.3
Methane (Simulation)	5.9	1.6	5.7

Figure 12: Effect of Reactor Temperature Variation on Methane Composition



	600 (°C)	675(°C)	750(°C)
Hydrogen (Experiment)	78.2	81.7	67.9
Hydrogen (Simulation)	76.9	81.2	72.6

Figure 13: Effect of Reactor Temperature Variation on Hydrogen Composition

Test 3: Changing steam to biomass ratio in dynamic model and comparing time taken for the product molar flow rate to stabilize

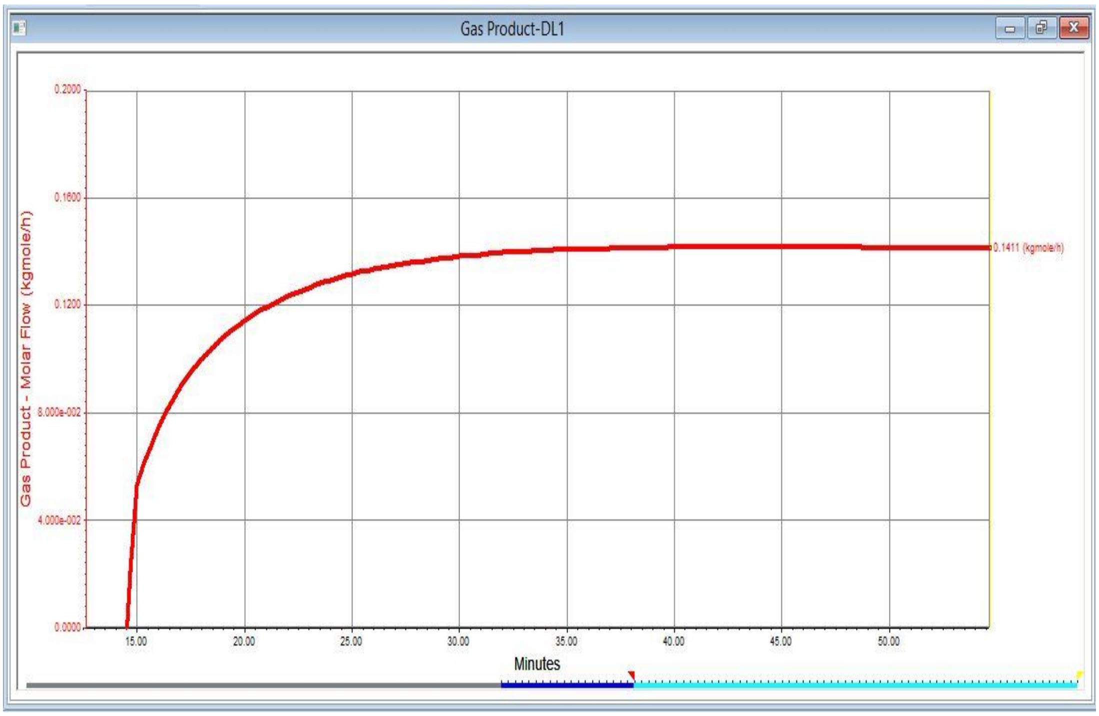


Figure 14: Rise in product flow rate when a step up of biomass flow rate was introduced from initial flow rate to 1.08 kg/hr

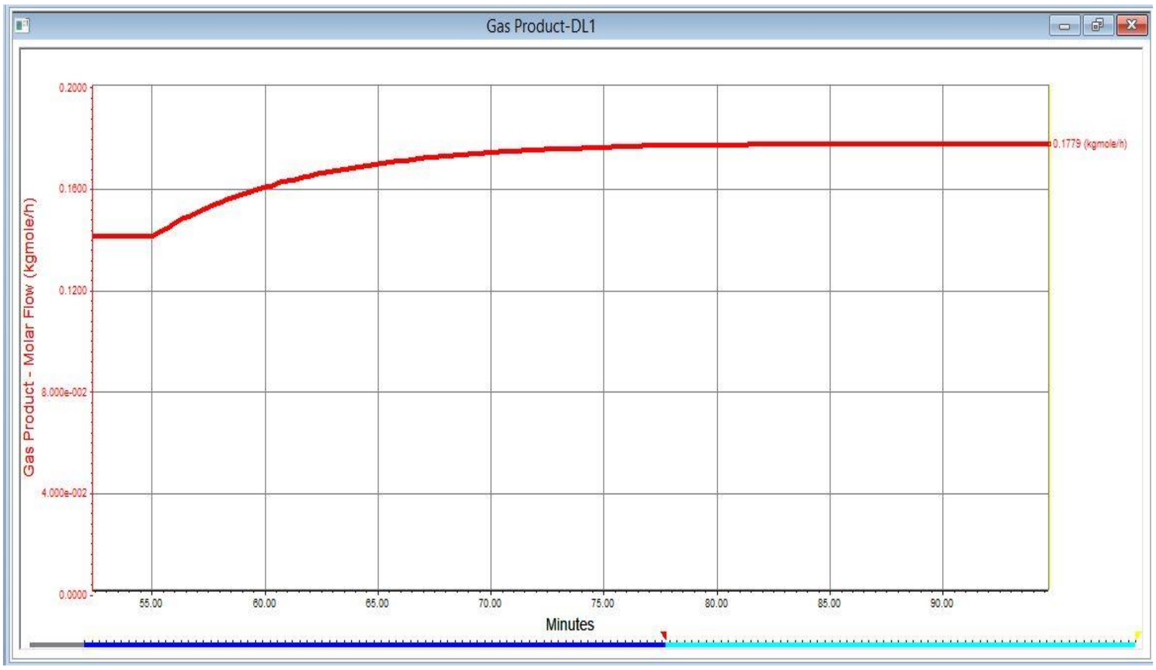


Figure 15: Rise in product flow rate when a step up of biomass flow rate was introduced from initial flow rate to 1.35 kg/hr

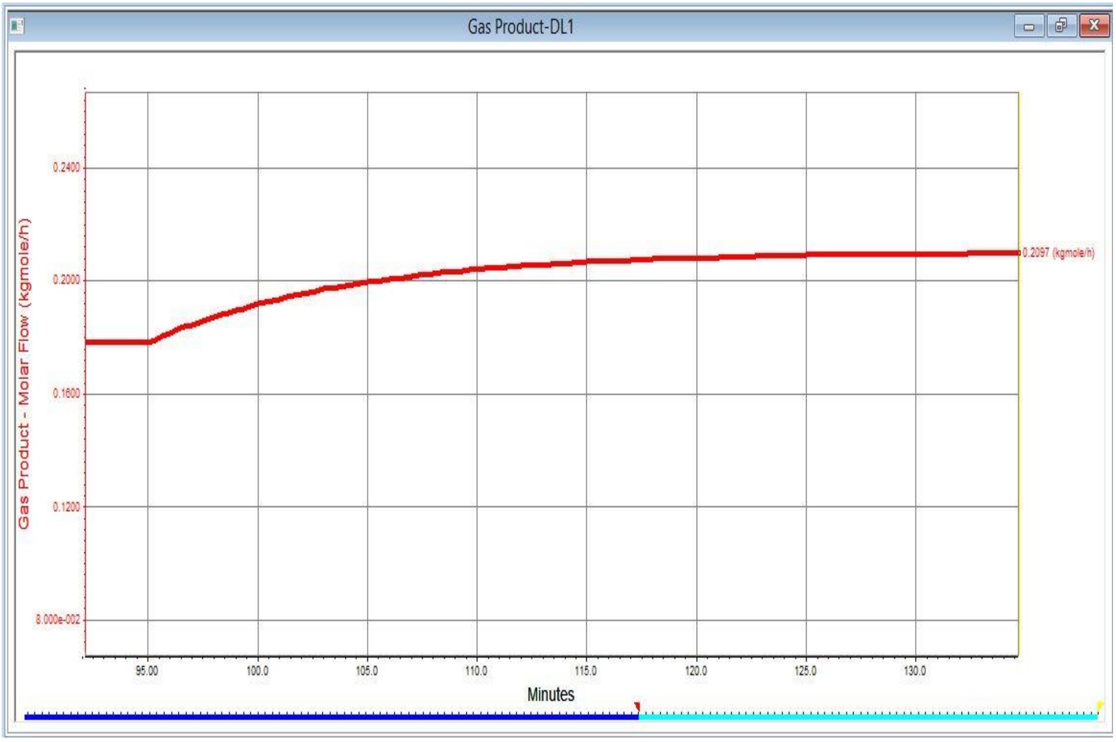


Figure 16: Rise in product flow rate when a step up of biomass flow rate was introduced from initial flow rate to 1.80 kg/hr

Test 4: Changing reactor Temperature in dynamic model and comparing time taken for the product molar flow rate to stabilize

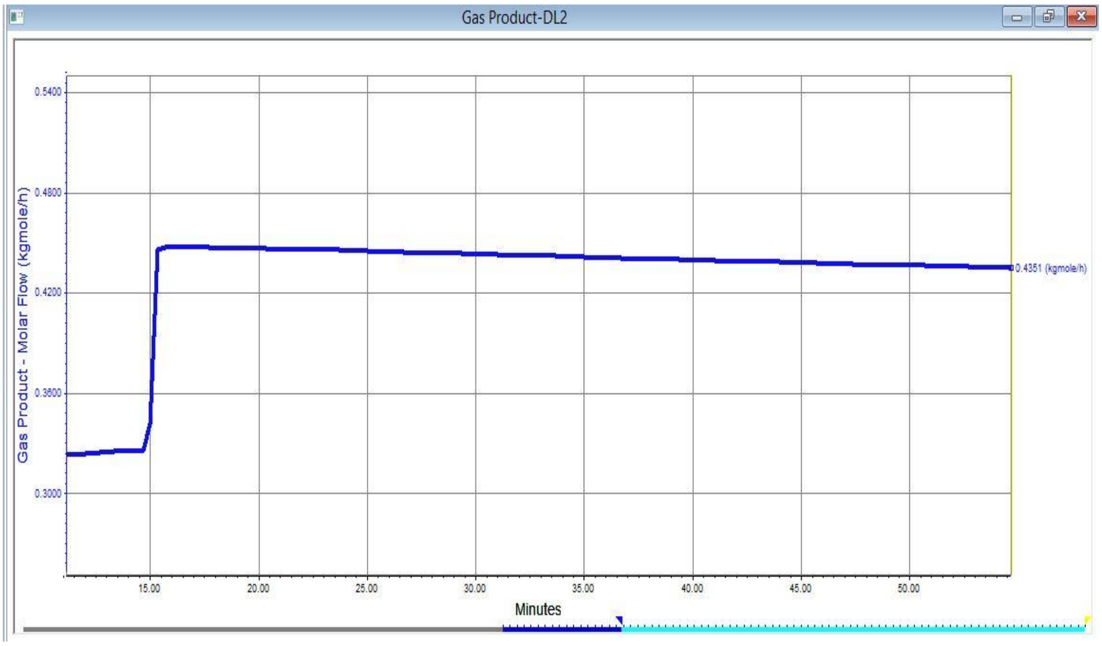


Figure 17: Rise of product flow rate when the step change was introduced from initial reactor temperature to 600°C

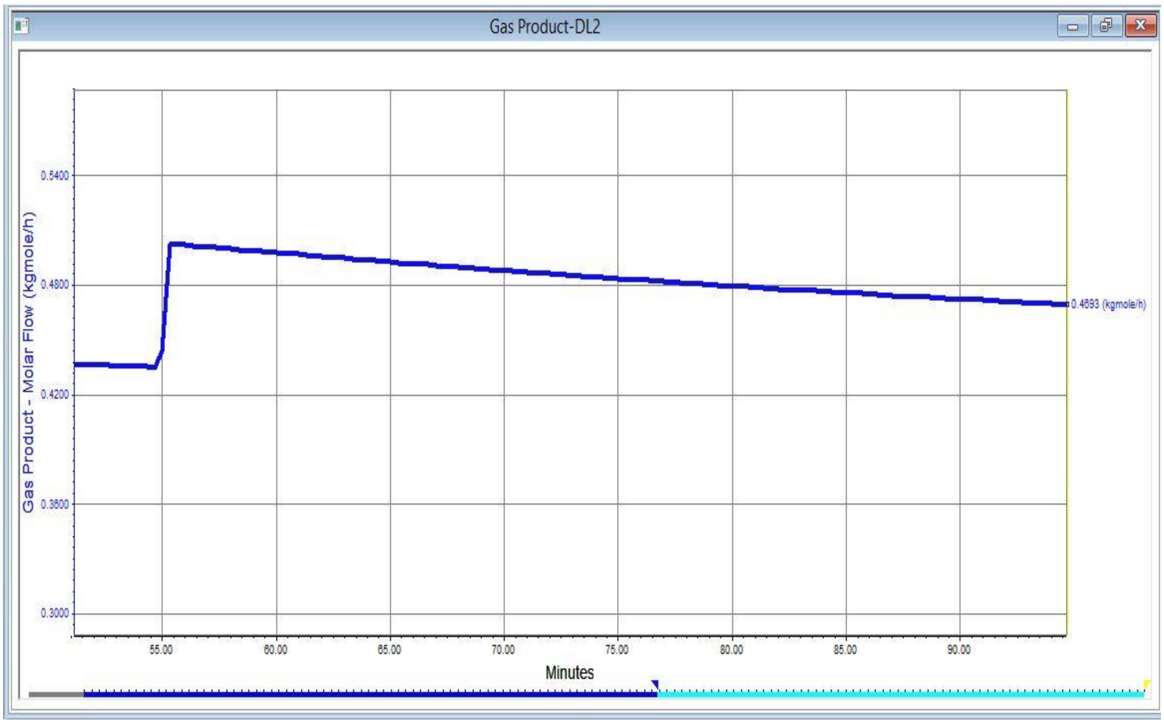


Figure 18: Rise of product flow rate when the step change was introduced from reactor temperature of 600°C to 675°C

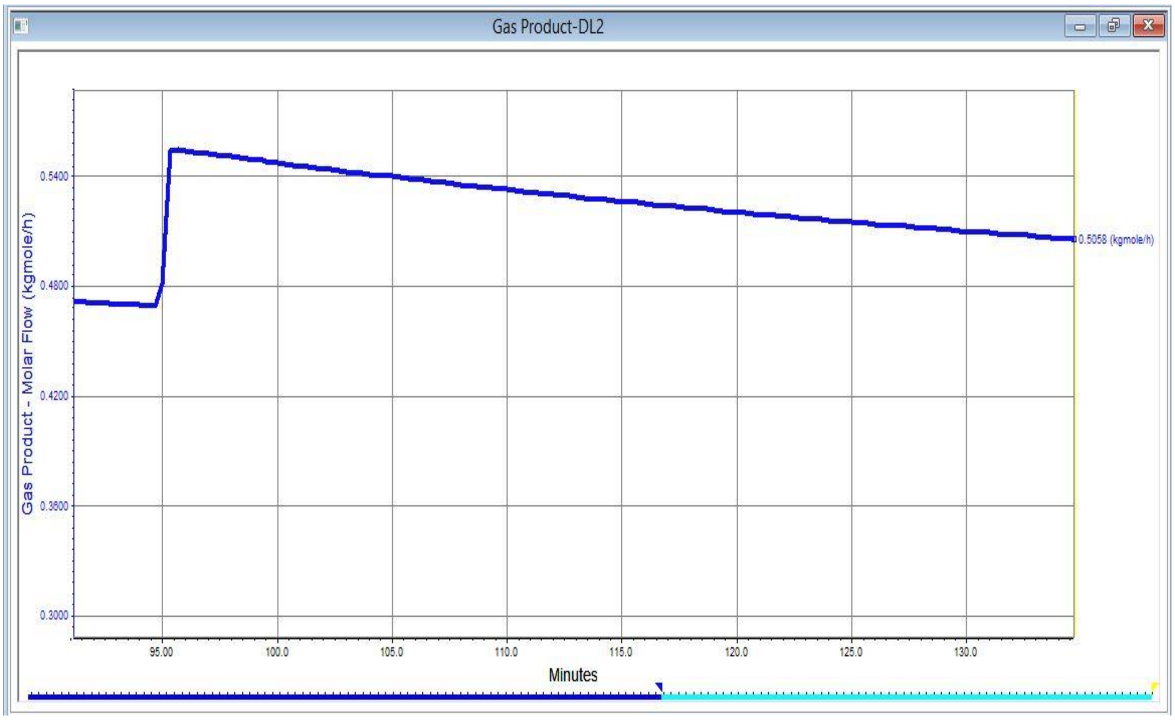


Figure 19: Rise of product flow rate when the step change was introduced from reactor temperature of 675°C to 750°C

Discussion Test 1: Changing steam to biomass ratio in steady state model and comparing composition of product with experimental results

In this test, when the Steam biomass ratio are varied we study the composition of the four components that are produced which are Carbon Monoxide (CO), Carbon Dioxide (CO_2), Methane (CH_4) and Hydrogen (H_2). The steam-biomass ratio is varied by increasing the flow rates of biomass into the gasifier from 1.08kg/hr to 1.35kg/hr to 1.8kg/hr. Both experimental and simulation results are tabulated in the graph. To determine the best biomass flow rate to be use in this plant is to ensure we get minimal amount of CO, CO_2 and CH_4 and the highest composition of H_2. This is because the energy content produced is measured in terms of composition of H_2 produced

For the composition of CO produce, both experiment and simulation results is displayed in Figure 6. It indicates that the amount of CO produces increases as the flow rate of biomass increases to 1.8kg/hr. The percentage difference also decreases between the experimental results and simulation results from 58.8% to 20% as the flow rate of biomass increases. The lowest amount of CO is found to be when the biomass flow rate is at 1.08 kg/hr for both experimental and simulation result

When the biomass flow rates are varied, there aren't any changes in the formation of CO_2 in the experimental results. 0% of CO_2 composition was found in the experimental results. Meanwhile the amount of CO_2 increases in the simulation results as the flow rate of biomass increases. This could be due to an error in the simulation which is not able to produce 0% of CO_2 in HYSYS. The lowest amount of CO_2 is found to be when the biomass flow rate is at 1.08 kg/hr for both experimental and simulation result

For the composition of CH_4 produce, both experiment and simulation results indicated that the amount of CO produces decreases as the flow rate of biomass increases to 1.8kg/hr. The percentage difference also increases between the experimental results and simulation results from 8.7% to 23.2% as the flow rate of biomass increases. The lowest amount of CH_4 is found to be when the biomass flow rate is at 1.80 kg/hr for both experimental and simulation result

Finally for the composition of H_2 produced, it can be seen that both experimental and simulation results produced, the composition of H_2 decreases as the flow rate of biomass increases. It records the highest among of H_2 composition when the biomass flow rate is at 1.08 kg/hr. This could be due to increase of CO composition as the biomass flow rate increases which affects the production of H_2 composition.

From the results of the biomass flow rate variation it can be seen that the lowest composition of CO and CO_2 and the highest composition of H_2 is produced when the biomass flow rate is set at 1.08 kg/hr. Except for CH_4 it produce the lowest amount of composition when the flow rate is at 1.80 kg/hr. CH_4 is found to be an intermediate level when the biomass flow rate is set to 1.08 kg/hr. Based on this factors, the most optimum biomass flow rate to be used in this plant is 1.08 kg/hr.

Discussion Test 2: Changing reactor temperatures in steady state model and comparing composition of product with experimental results

In this test, when the temperature are varied we study the composition of the four components that are produced which are Carbon Monoxide (CO), Carbon Dioxide (CO_2), Methane (CH_4) and Hydrogen (H_2). The temperatures are varied from the initial temperature of 600°C to 675°C and finally 750°C. Both experimental and simulation results are tabulated in the graph. . To determine the best reactor temperature to be use in this plant is to ensure we get minimal amount of CO, CO_2 and CH_4 and the highest composition of H_2. This is because the energy content produced is measured in terms of composition of H_2 produced

For the composition of CO produce, both experiment and simulation results indicated that the lowest amount of CO produce is at 675°C despite the simulation results varies 83% from the experimental results. Meanwhile at 750°C, CO at both experimental and simulation results shows very similar results with a difference of 4.4%. The lowest composition of CO is found to be when the reactor temperature is set to 675°C as can be seen in Figure 10

When temperatures are varied, there isn't much variation in the formation of CO_2. At 600°C and 675°C 0% of CO_2 composition was found in the experimental results while traces of CO_2 were found in the simulation results. This could be because of potential errors that occur in the simulation which is not as exact as the real performance. However at 750°C CO_2 was found in both experimental and simulation results with a difference of 6.5%. In the simulation results, the lowest composition of CO_2 is found to be when the reactor temperature is set to 600°C as can be seen in Figure 11 while the experimental results shows that there is 0% composition found at all 3 temperatures

For the composition of CH_4 produce in the experimental results, it can be seen that the composition decreases at a steady rate of 1.4%-1.5% as the temperature increases. Meanwhile in the simulation results, at both 600°C and 750°C the composition of CH_4 is rather similar but there is a huge dip at 675°C. The lowest composition of CH_4 in the simulation is found to be when the reactor temperature is set to 750°C as can be seen in Figure 12 while in the experimental results shows that the lowest composition amount is found at 675°

Finally for the composition of H_2 produced, it can be seen that both experimental and simulation results produced are very consistent at all 3 temperature variation with both experimental and simulation results showing almost identical results at 675°C which is also the highest amount of H_2 and it can be seen in Figure 13.

Based on the results obtain it can be seen that there are some difference in terms of the simulation results and experimental results as especially for the CO_2 and CH_4. This could be due to some error in HYSYS during raising the temperature. Therefore based on the data collected, 675°C has been determined as the best temperature to run the plant as most of the experimental results supports this value and half of the simulation as well

Discussion Test 3: Changing steam to biomass ratio in dynamic model and comparing time taken for the product molar flow rate to stabilize

The discussion for the dynamic model will focus more on the rise in product flow rate when a step change is introduce and how long it takes to reach steady state. The percentage composition of the product in the dynamic model remains the same as in the steady state model.

In Figure 14, a step up in the biomass flow rate into the reactor was introduced. The step up was from the initial flow rate increasing it to 1.08 kg/hr. As soon as the step up was introduced, there was an immediate rise in the product molar flow rate. The product molar flow rate increase from 0.05 kgmole/hr to a final product flow rate of 0.1411 kgmole/hr. It can be seen that it takes the system 20 minutes to stabilize as the step change was introduce at the 15th minute and the product molar flow rate beings to stabilize on the 35th minute. The system was allowed to run for a total of 45 minutes and this was done for all the step changes. The next step change is introduced at the 55th minute

The next step up was introduced in the biomass flow rate from 1.08 kg/hr to 1.35 kg/hr. In Figure 15, it can be seen that the rise in the product molar flow rate is smaller compared to Figure 14. This is because the system is already being ran for 55 minutes and the step up change introduce isn't a large change. Therefore the rise in product molar flow rate isn't as great as Figure 14. It can be seen that it takes the system 20 minutes to stabilize as the step change was introduce at the 55th minute and the product molar flow rate beings to stabilize on the 75th minute. The final product molar flow rate is found to be at 0.1779 kgmole/hr. The system was allowed to run for a total of 45 minutes and this was done for all the step changes. There is an increase of 0.0368 kgmole/hr of product flow rate when this step change was introduced. The next step change is introduced at the 95th minute.

The next step up was introduced in the biomass flow rate from 1.35 kg/hr to 1.8 kg/hr. In Figure 16, it can be seen that the rise in the product molar flow rate is almost equal compared to Figure 15. This is because the step up introduce is almost the same value. Therefore the rise in product molar flow rate is almost equal to Figure 15. It can be seen that it takes the system 20 minutes to stabilize as the step change was introduce at the 95th minute and the product molar flow rate beings to stabilize on the 115th minute. The final product molar flow rate is found to be at 0.2097 kgmole/hr. The system was allowed to run for a total of 45 minutes and this was done for all the step changes. There is an increase of 0.0318 kgmole/hr of product flow rate when this step change was introduced.

From the data gathered from the dynamic simulation of biomass flow rate variation, it can be seen that it takes the system about 20 minutes to reach its new steady state level when a step up change is introduce.

Discussion Test 4: Changing reactor Temperature in dynamic model and comparing time taken for the product molar flow rate to stabilize

In Figure 17, a step up in the reactor temperature was introduced. The step up was from the initial temperature increasing it to 600°C. As soon as the step up was introduced, there was an immediate rise in the product molar flow rate. The product molar flow rate increase from 0.32 kgmole/hr to a final product flow rate of 0.4351 kgmole/hr. The rise in product molar flow rate is very sharp when the step up change was introduced. It can be seen that it takes the system 7 minutes to reach its peak product molar flow rate before the product molar flowrate begins to decline slowly over the course of 45 minutes. This is because due to the temperature change is introduced, the product molar flow rate continues to adjust to its new reactor temperature. After 45 minutes, the final product molar flow rate is at 0.4351 kgmole/hr.

In Figure 18, a step up in the reactor temperature was introduced. The step up was from the 600°C increasing it to 675°C. As soon as the step up was introduced, there was an immediate rise in the product molar flow rate. The product molar flow rate increase from 0.4351 kgmole/hr to a final product flow rate of 0.4950 kgmole/hr. The rise in product molar flow rate is very sharp when the step up change was introduced. It can be seen that it takes the system 7 minutes to reach its peak product molar flow rate before the product molar flowrate begins to decline slowly over the course of 45 minutes. This is because due to the temperature change is introduced, the product molar flow rate continues to adjust to its new reactor temperature. After 45 minutes, the final product moar flow rate is at 0.4693 kgmole/hr. After 45 minutes, the increase in product molar flow rate from 600°C to 675°C is 0.0342kgmole/hr.

In Figure 19, a step up in the reactor temperature was introduced. The step up was from the 675°C increasing it to 750°C. As soon as the step up was introduced, there was an immediate rise in the product molar flow rate. The product molar flow rate increase from 0.4693 kgmole/hr to a final product flow rate of 0.5450 kgmole/hr. The rise in product molar flow rate is very sharp when the step up change was introduced. It can be seen that it takes the system 7 minutes to reach its peak product molar flow rate before the product molar flowrate begins to decline slowly over the course of 45 minutes. This is because due to the temperature change is introduced, the product molar flow rate continues to adjust to its new reactor temperature. After 45 minutes, the final product moar flow rate is at 0.5058 kgmole/hr. After 45 minutes, the increase in product molar flow rate from 675°C to 750°C is 0.0365 kgmole/hr

The common trait between the results obtain for the dynamic simulation for temperature variance is that, the rise in product molar flow rate after a step change is introduce is very steep and very fast and once it reach the peak of the product molar flow rate, the molar flow rate begins to decline slowly over the course of 45 minutes. This could be due to some errors that may have occurred in HYSYS and the difficulties to control the temperature rise in HYSYS. With the assistance of a difference software like ASPEN PLUS could help provide better results

CHAPTER 5: CONCLUSION

Biomass is one of the leading alternative sources of energy that can replace fossil fuel whereby its main advantage is that it is a renewable source. The biomass gasification system is an environmental friendly process whereby it can reduce the emission of carbon dioxide gas. Biomass gasification system is a system that converts carbonaceous materials into gaseous fuels.

There is a present available unit of this system available in UTP which is located in Block P. It uses palm kernel shell as its main feedstock. This is due to the fact palm kernel shell ability in producing high amount of hydrogen which is the carrier energy. Currently no proper steady state or dynamic model has been developed for this plan. Thus making this research very vital for UTP to help improve their understanding of this plant.

Based on the series of test conducted on the steady state model and analyzing the results it can be seen that the best operating conditions for the biomass gasification plant is at 675°C and using 1.08kg/hr of biomass flow rate. It can be seen that the composition of CO, CO_2 is found to be at its lowest although the amount of CH_4 is at an intermediate range. The most important factor in deciding this operating condition is that the amount of H_2 produce is found to be at its peak at these conditions when the biomass used is palm kernel shell.

In the Dynamic Model, it can be concluded that the simulation reacts very well when there is a biomass step change introduce. From the simulation results, it can be noted that it takes the system 20 minutes to reach steady state before the product molar flow rate stabilizes. Meanwhile the same does not occur when a temperature step change is introduced. It can be seen that there in an immediate rise in the product molar flow rate which is about 7 minutes before it hits the peak molar flow rate. Over the course of 45 minutes, the product molar flow rate begins to decline slowly. The system does not stabilize properly during these 45 minutes. It may require the system a longer time to reach steady state.

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