Simulation Studies of Biomass Gasification System

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CERTIFICATION OF APPROVAL

Control of Biomass Gasification System

by
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CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, tha 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.

MOHAMAD FAIQ BIN MD AMIN

ABSTRACTS

Biomass gasification plant with steady state and dynamics modelling exhibits promising prospects for the process modelling of the system. Extensive studies are required in understanding the biomass gasification system using extensive values of parameters. Previous works are only focusing on the experiment in isolated pilot plant while process modelling in steady state system and dynamics state system for hydrogen production using oil palm empty fruit kernel using Aspen Plus is another steps forward in using simulation study. Several variables are been identified that able to increase the production of hydrogen however because of limited time and knowledge the research was done focusing on one variable. Temperature has been manipulated to increase the production of hydrogen plus enhance carbon conversion efficiency. It plays an important role in the gasification reaction as it increase the conversion of hydrogen respect to the biomass used. While, increasing steam-to-biomass ratio increases hydrogen and carbon monoxide production hence decreases carbon dioxide and carbon conversion efficiency. Previous papers show the increment from 80.89% to 82.78% as result of increasing the biomass to steam ratio. This project focused on at least achieving the values above as validation of the simulation studies.

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Introduction

1.1 Background of Study

The project is related to gasification system focusing in modelling a steady state reaction to study the biomass gasification system. The gasification is a thermochemical conversion process to produce, from carbonaceous fuel, a gas product with a useful heat value that can be applied as fuel gas or synthesis gas for later use. The thermochemical conversion modifies the chemical structure of biomass through high temperature. The gasification agent enables that the feeding current be converted quickly into gas through different homogeneous and heterogeneous reactions. The resulting gas contains CO_2, CO, H_2, CH_4, H_2O, hydrocarbons, still gases present in the gasification agent, several contaminants such as small particles of carbon matter, ashes and tar. The produced fuel gas can be used to produce electric energy in gas turbines, engines, furnaces, or else, be the input to produce several substances, among them ammonia, methanol, gasoline, diesel, ethanol, etc. [1]. An advantage of using biomass as energy source is its carbon neutrality. Consequently the managed usage of biomass as energy source does not increase the quantity of carbon dioxide in the atmosphere.

This study is important because of it will provide more area of research as the modelling the gasification plant is working of similar system that applied in the existing plant. Several literatures show the effect of temperature, biomass to steam ratio, adsorbent to biomass ratio, biomass particle sizes, and catalyst used. However, these variables are being studied at experimental level and using empirical result. In other hand, modelling will provide the thermodynamics and kinetics study of this system that will affect the reaction. Although this research will not go into kinetics and thermodynamics studies but using material and energy balance models sufficient as the first step. This study aims only the gasification system of fluidized bed gasifier to as extensive study for the steady state behavior.

1.2 Problem Statement

Dynamics model for gasification system is not frequently use in modeling the system, this is because steady state model has simpler and predictable interaction when used in developing gasification system. Thus, modelling steady state simulation is crucial in taking first step to understand dynamics model. Simulation of biomass gasification system requires process flow diagram to be constructed and the parameters that suitable to the operating condition. Various behavior of output is studied when we manipulate the parameters. Therefore, it important to understand the steady state or static behavior before designing and observing dynamics behavior.

1.3 Objective

- To develop steady state simulation of a gasification system in a plant.
- To design & model existing pilot plant for the gasification system using Aspen Plus simulation.
- To evaluate the performance of the simulation system.

1.4 Scope of Study

- Develop a reliable model for gasifier static behavior,
- Predict process output in controlled operations,

CHAPTER 2

Literature Review

2.0 Biomass Gasification Process

Gasification process is recognised as one of the most promising technologies to convert biomass into energy and value-added products in an integrated biorefinery [2]. Therefore, it is essential to further analyse and optimise the gasification process in order to increase the overall performance of the integrated biorefinery. Gasification typically operates in a temperature range of 600-1400 degree Celsius [3], with a controlled supply of oxygen and/or steam to convert biomass into a gaseous mixture which is commonly known as synthesis gas or syngas. These gas mixtures consist of carbon dioxide (CO_2), steam (H_2O), methane (CH_4), carbon monoxide (CO) and hydrogen (H_2). Other by-products include gaseous hydrocarbons (CHs), tars, char, inorganic constituents, and ashes were also produced from the gasification process other than production of syngas [4]. Syngas produced from biomass gasification through the robust thermal conversion can be used as feedstock for the production of liquid fuels and chemicals as well as generation of heat and power [5]. Waste heat generated in the biomass gasification system can be recovered in utility systems through heat integration.

The chemistry of biomass gasification is quite complex. Broadly speaking, the gasification process consists of the following stages [6–9]:

In drying stage, the moisture content of the biomass is reduced. Typically, the moisture content of biomass ranges from 5% to 35%. Drying occurs at about 100–200 °C with a reduction in the moisture content of the biomass of <5%. While in devolatilisation or pyrolysis stage is an essential the thermal decomposition of the biomass in the absence of oxygen or air. In this process, the volatile matter in the biomass is reduced. This results in the release of hydrocarbon gases from the biomass, due to which the biomass is reduced to solid charcoal. The hydrocarbon gases can condense at a sufficiently low temperature to generate liquid tars.

This oxidation reaction between solid carbonised biomass and oxygen in the air, resulting in formation of CO_2. Hydrogen present in the biomass is also oxidised to generate water. A large amount of heat is released with the oxidation of carbon and hydrogen. If oxygen is present in substoichiometric quantities, partial oxidation of carbon may occur, resulting in the generation of carbon monoxide.

In the absence (or substoichiometric presence) of oxygen, several reduction reactions occur in the 800–1000 °C temperature range. These reduction reactions are mostly endothermic. The main reactions in this category are as follows:
A general scheme of the gasification phases, which is not intended to be exhaustive, is shown in Figure 1 and is built following the wet wood in its transformation to ash and released products [10].

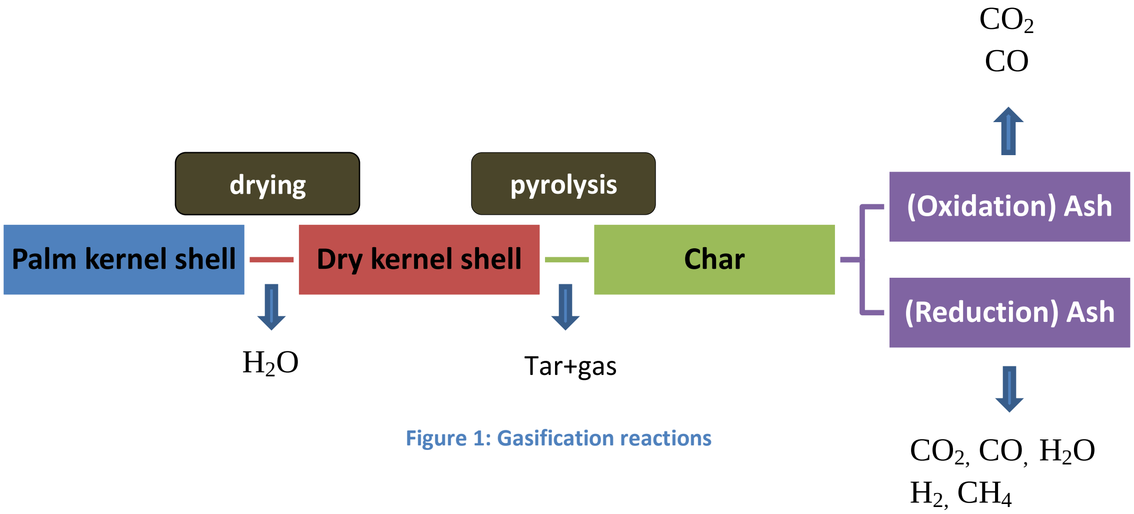


Figure 1: Gasification reactions

Figure 1.0 Gasification phases shows the kernel shell is dried and releases water. The pyrolysis converts the dry kernel shell into char (a solid substance rich in carbon), tar and other gases. The char faces reduction and oxidation. The actual sequence of these two processes is defined by the gasifier type. During reduction char is converted mainly into carbon monoxide, hydrogen, methane, carbon dioxide and water. Oxidation is the combustion of char and releases carbon monoxide, carbon dioxide and energy. The remaining solid that does not react is called ash. The gasification product is a gas mixture with a relevant heating value called producer gas.

2.1 Fluidized bed gasifier

The gasification agent, which is blown at high velocity from the bottom, mixes biomass particles, oxidizer, hot gases and the bed material. The bed material consists of very small particles of inert material (a siliceous sand), which avoid sinterization, and catalysts, which decrease the tar amount and control the syngas composition. The temperature is very homogeneous and usually lower than in the fixed bed gasifiers, being around 750-900°C. The gasification phases are not spatially localized. The main advantages of using this type of gasifier are very high heat transfer and high reaction velocity due to high turbulence rate. The carbon conversion is high and we can manipulate the biomass moisture instantaneously. However, this type of gasifier generates a high tar amount because of low temperature used [11].

This promising technology has received increasing attention in the past two decades due to the growing demand for clean fuels and chemical feedstock, as well as the need for reducing dependency on fossil fuels, lowering greenhouse gas emissions and disposing of existing wastes. Plus, each year, municipalities spend millions of dollars collecting and disposing of wastes, such as yard wastes (grass clippings and leaves) and construction and demolition debris. While some municipalities compost yard wastes, this takes a separate collection by a city an expense many cities just can’t afford. Yard waste and the construction and demolition debris can take up valuable landfill space shortening the life of a landfill. Many cities in the northeast face a shortage of landfill space. With gasification, this material is no longer a waste, but a feedstock for a biomass gasifier. And, instead of paying to dispose of and manage a waste for years in a landfill, using it as a feedstock reduces disposal costs and landfill space, and converts those wastes to power and fuels[12].

2.2 Simulation for the gasification system

Some authors, trying to avoid complex processes and develop the simplest possible model that incorporates the principal gasification reactions and the gross physical characteristics of the reactor, have developed models using the process simulator Aspen Plus [101]. Aspen Plus is a problem-oriented input program that is used to facilitate the calculation of physical, chemical and biological processes. It can be used to describe processes involving solids in addition to vapour and liquid streams. Aspen Plus makes model creation and updating easier, since small sections of complex and integrated systems can be created and tested as separate modules before they are integrated. This process simulator is equipped with a large property data bank containing the various stream properties required to model the material streams in a gasification plant, with an allowance for the addition of in-house property data. Where more sophisticated block abilities are required, they can be developed as FORTRAN subroutines. Aspen Plus has been used to simulate coal conversion; examples include methanol synthesis [13,14], indirect coal liquefaction processes [15], integrated coal gasification combined cycle (IGCC) power plants [16], atmospheric fluidised-bed combustor processes [17], compartment fluidised-bed coal gasifiers [18], coal hydrogasification processes [19] and coal gasification simulation [20]. It has also been used to model and simulate a type pyrolysis unit within a gasification-based plant (Go´mez et al. [21]).

3.0 Methodology

3.0 Project Activities

Aspen Plus Modelling

- Modelling based on Material and Energy Balance
- Flowsheeting based on plant flowsheet

Acquire Biomass Gasification Plant Information

- Insert input physical properties (Temperature,Pressure, Flowrates & Composition)
- Design based on PFD & P&ID.

Data gathering and Results

- Apply sensitivity analysis on different parameters
- Acquire data and results from the simulation
- Tabulate the data and analyze critically

3.1 Research Methodology

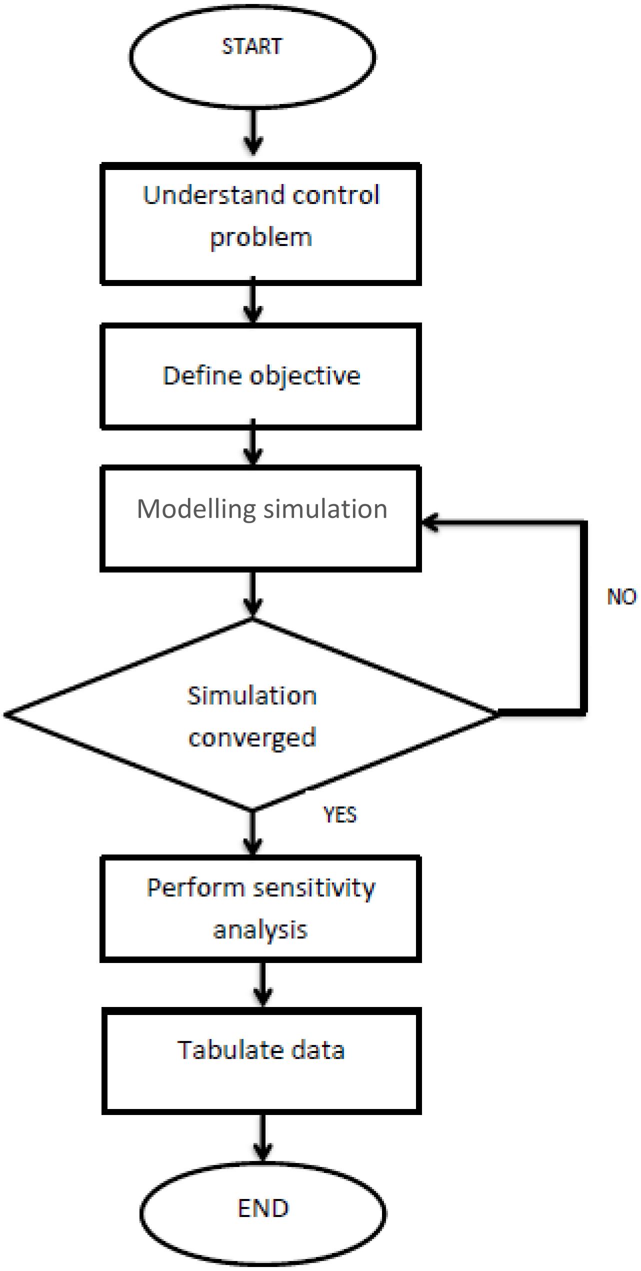


Figure 3.1.1: Flowchart of simulation done in Aspen Plus

3.1.0 Aspen Plus specification

In Aspen Plus, design specification plays similar role as for the feedback controller. The physical controller in this steady state system will not appear but rather being fixed or manipulated in design specification option. Design specification allows user to set the value of a calculated flowsheet quantity to a particular value so that objective is achieved by manipulating a specified input variable. These are the steps using design specifications:

1. Identify measured variable.
2. Specify objective function (specification) and goal (target).
3. Set tolerance for objective function.
4. Specify manipulated (varied) variables.
5. Specify range of manipulated (varied) variable.

The following assumptions were considered in modeling the gasification process:

- The gasification process is isothermal and steady state.
- Biomass de-volatilization is instantaneous in comparison to char gasification.
- The biomass particles are spherical and are not affected in course of the reaction.
- All the gases are uniformly distributed within the emulsion phase
- Char consists of only carbon and ash.
- Char gasification starts in the bed and ends in the freeboard.

The objective of the specification is that it equals the calculated value (Specified Value - Calculated Value = 0). Specifications must also have a tolerance within which the objective function relation must be satisfied. Therefore, the actual equation that must be satisfied is

Manipulated variable

Type: Block-Var

Block: REACTR1

Variable: TEMP

Sentence: PARAM

Units: C

Manipulated variable limits

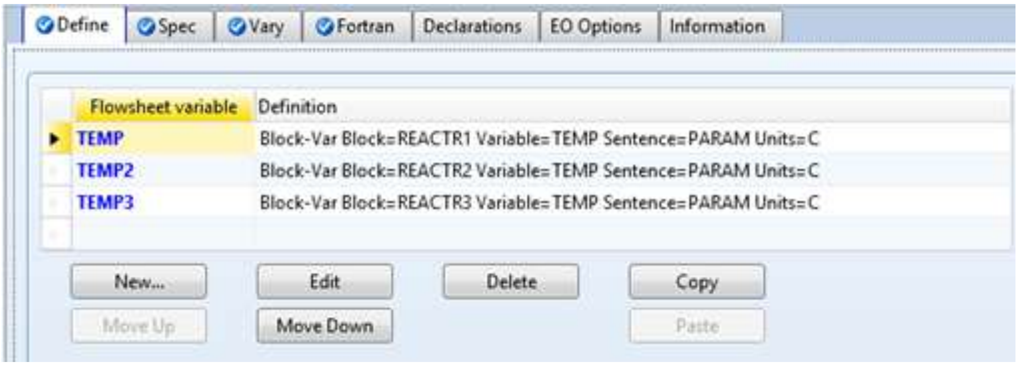
Lower: 650

Upper: 700

Step size: 0.1

Maximum step size: 0.5

Figure 2.1.2: Variation of temperature in Reactor 1



Flowsheet variable	Definition
TEMP	Block-Var Block=REACTR1 Variable=TEMP Sentence=PARAM Units=C
TEMP2	Block-Var Block=REACTR2 Variable=TEMP Sentence=PARAM Units=C
TEMP3	Block-Var Block=REACTR3 Variable=TEMP Sentence=PARAM Units=C

Figure 3.1.3: Temperature feedback control in three reactors.

For all three gasifiers in the plant, the units that are used in Aspen Plus are Rstoic BLOCK. This Aspen Plus's reactor block enables the user to include the reactions and conversion occurred in gasifier. The equations that are inserted in simulation are:

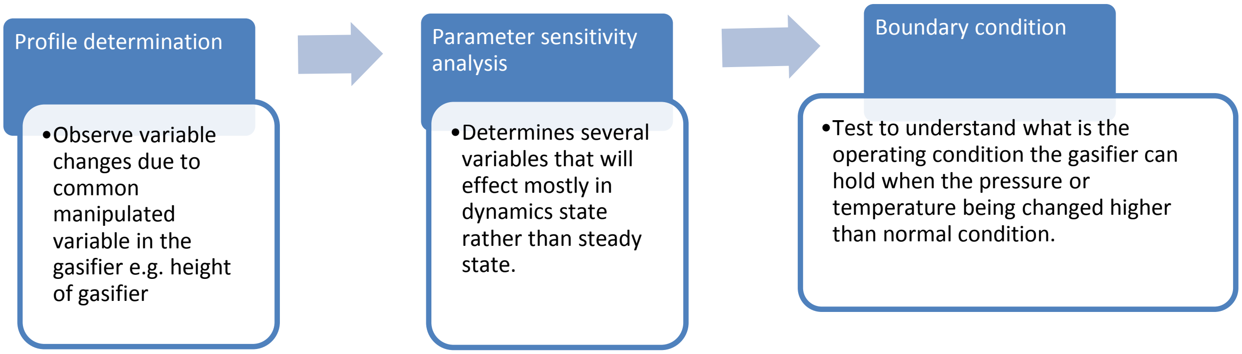
$$C + H2O \rightarrow CO + H2 \tag{1}$$

$$C + 2H2 \rightarrow CH4 \tag{2}$$

$$CH4 + H2O \rightarrow CO + 3H2 \tag{3}$$

$$CO + H2O \rightarrow CO2 + H2 \tag{4}$$

3.1.1 Study the Statics Behaviors of the Gasification System



Profile determination

- Observe variable changes due to common manipulated variable in the gasifier e.g. height of gasifier

Parameter sensitivity analysis

- Determines several variables that will effect mostly in dynamics state rather than steady state.

Boundary condition

- Test to understand what is the operating condition the gasifier can hold when the pressure or temperature being changed higher than normal condition.

Figure 3.1.1: Few consideration to understand the dynamic behavior of the particular system.

Simulation strategies were used because it easier to model a gasification system especially when using Aspen Plus software. After the modeling is done we will proceed with include control strategy to this dynamics model using PID controller. Therefore several tests need to be carried out with static/steady state model in order to simplify the formation of a dynamics model.

3.1.1.1 Profile Determination

This part discussed about parameters of the gasification plant specifically in UTP to understand the operating condition of this plant.

Table 3.1.1.1: Experimental results of difference in temperature.

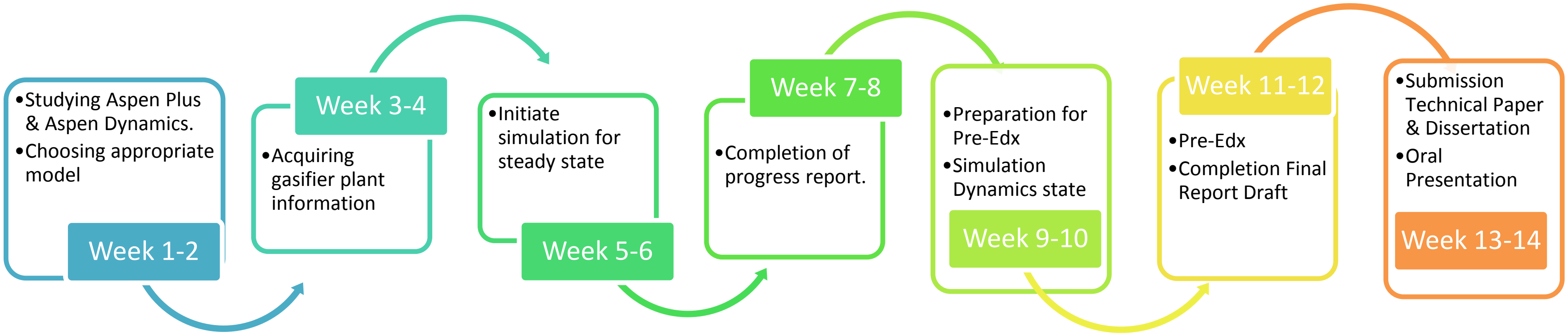
Parameters	**Response Variable**		
Temperature	**675**	**675**	**675**
Biomass feed rate (kg/h)	**1.8**	**1.35**	**1.1**
Steam/biomass (wt/wt)	1.5	2	2.5
Gas composition (vol%, Dry N2 free)			
H2	80.97	82.1	82.61
CO	10.49	6.45	5.45
CO2	0	0	7.99
CH4	8.63	11.43	3.95
H2 Yield (g/kg biomass)	28.69	80.39	97.93
Gas yield (m3/Kg biomass)	0.43	1.19	1.44
Char yield (g/kg biomass)	32.55	27.33	26.08
Gasification efficiency (%)	10.34	24.66	43.08
Carbon conversion efficiency (%)	8.03	20.96	24.66
Lower heating value (MJ/Nm3)	13.14	13.78	11.02

Table 3.1.1.2: Parameters of the Reactor

Parameter	**Value**
Pressure	Atmospheric
Temperature	650-700 °C.
Type of Reactor	Fluidized Bed Reactor
Diameter of Reactor	0.15 m
Height of Reactor	2.5 m
Feed of Biomass	0.1e0.5 g/s
Gas Velocity	0.21 m/s

Above are the parameters for pilot scale fluidized bed gasification system used in UTP to produce hydrogen from palm shell kernel.

3.2 Key Milestones



Week 1-2
- Studying Aspen Plus & Aspen Dynamics.
- Choosing appropriate model

Week 3-4
- Acquiring gasifier plant information

Week 5-6
- Initiate simulation for steady state

Week 7-8
- Completion of progress report.

Week 9-10
- Preparation for Pre-Edx
- Simulation Dynamics state

Week 11-12
- Pre-Edx
- Completion Final Report Draft

Week 13-14
- Submission Technical Paper & Dissertation
- Oral Presentation

3.3 Gantt Chart

No	Detail	Weeks														
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	Designing control strategies	🟦	🟦	🟦	🟦	🟦	🟦	🟧								
2	Submission of Progress Report							🟧	🟥							
3	Applying dynamics control							🟧	🟦	🟦	🟦	🟦	🟦			
4	Pre-EDX							🟧				🟥				
5	Submission of Draft Report							🟧					🟥			
6	Submission of Dessertation							🟧						🟥		
7	Submission of Technical Paper							🟧						🟥		
8	Oral Presentation							🟧							🟥	
9	Submission of Project Dissertation							🟧								🟥

CHAPTER 4

RESULT & DISCUSSION

Table 4.1: Gas Composition in three reactors

Gas Composition	REACTR3	REACTR2	REACTR1
C	0.00351676	0.00261717	0.0149083
O2	0.0243515	0.012214	0.0243515
CO	0.0343997	0.0120576	0.0223625
CO2	0.0268004	0.0120576	0
CH4	0.00982475	0.0106556	0.0372708
H2	0.2189706	0.0903037	0.0318388
N2	0.1005576	0.0503322	0.0339561
H2O	0.2375603	0.1267773	0.0856053
S	0.000151562	7.60E-05	0.00015156

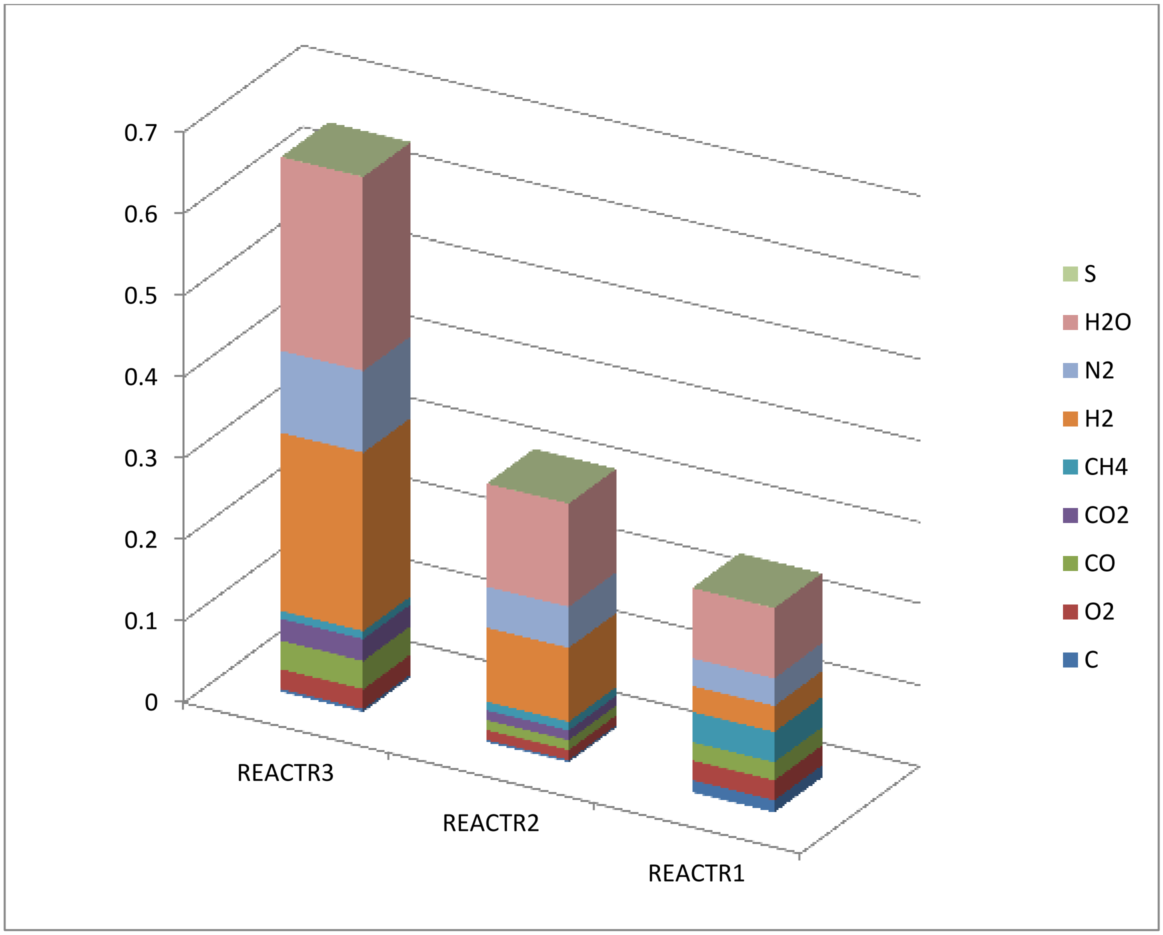


Figure 4.2: Simulated product gas composition flowrate.

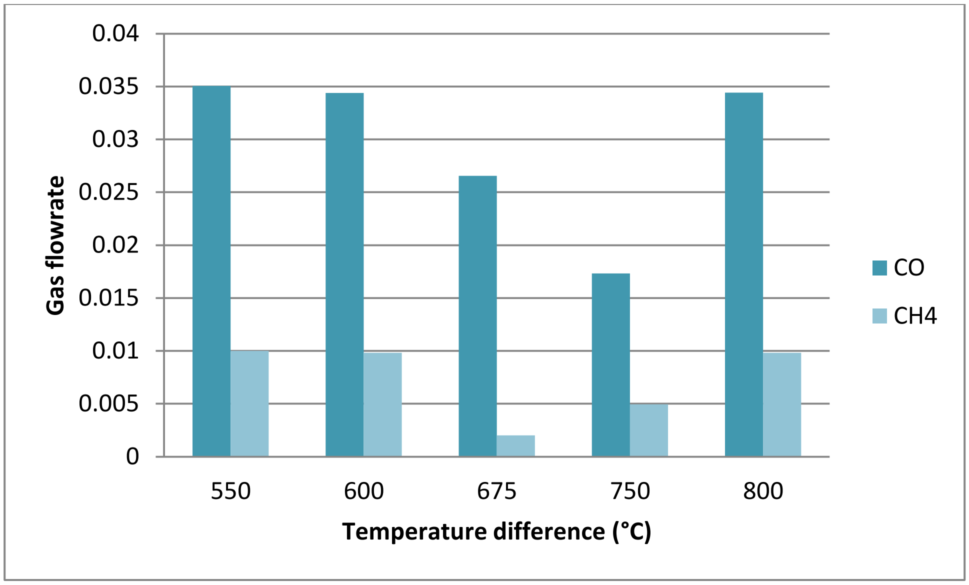


Figure 4.3: Gasses vs Temperature

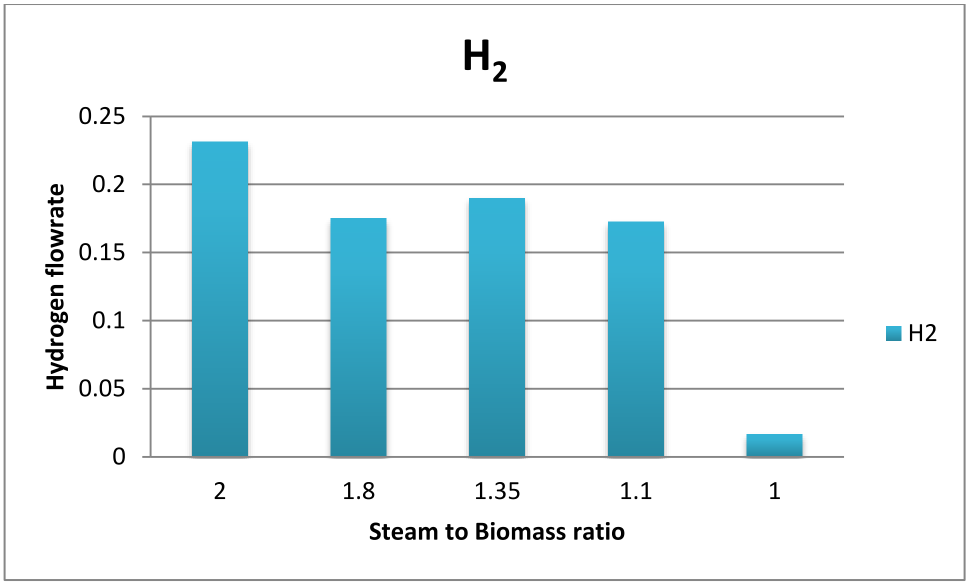


Figure 4.4: Hydrogen vs steam to biomass ratio

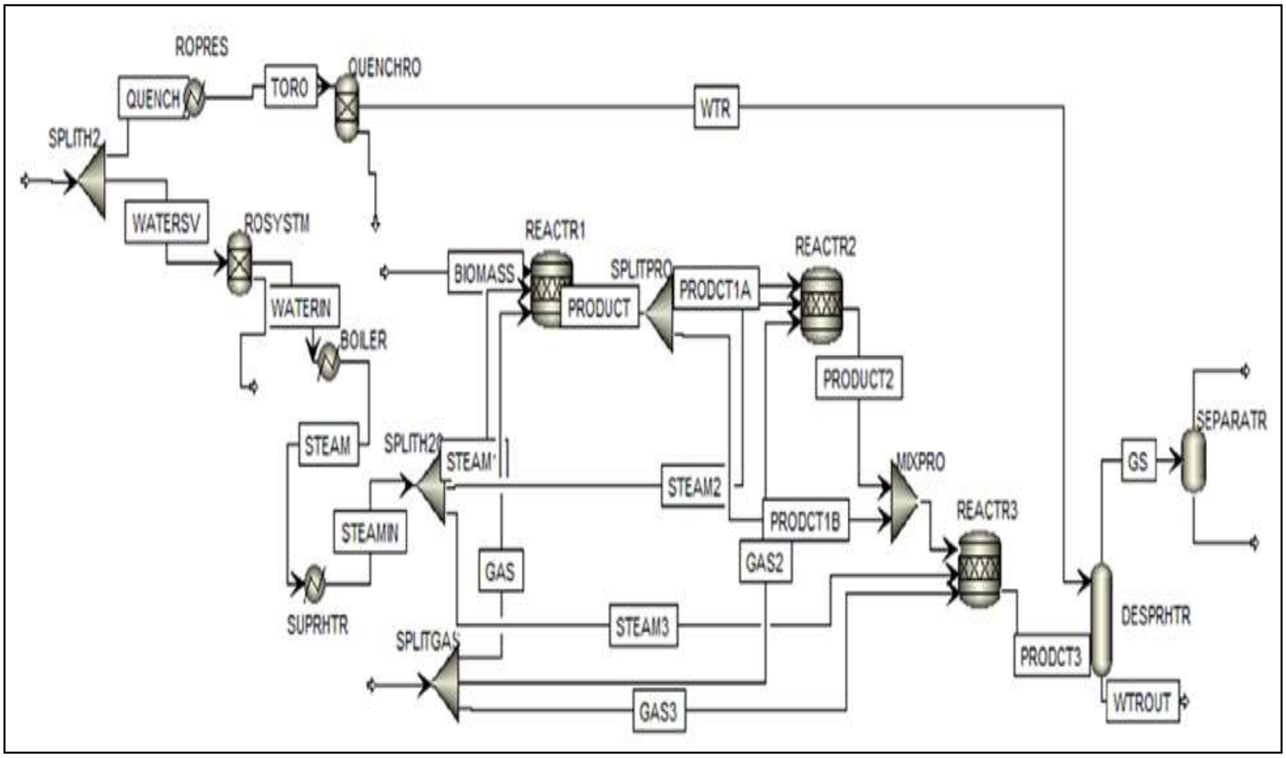


Figure 4.5: Shows flowsheet of Gasification Plant using Aspen Plus Simulation.

Figure above is the flowsheet of biomass gasification plant, this flowsheet is based on the process flow diagram (PFD) and piping and instrumental diagram (P&ID) done in Aspen Plus modelling. There are three reactors aligned in parallel to increase the conversion of biomass to hydrogen gas. Steam was generated by superheat at very high temperature while the inert gas purged before the reaction to remove the gas or liquid before the feedstock inserted.

DISCUSSIONS

Using ASPEN PLUS simulator and fluidized bed gasifier model the simulation for whole plant was studied and it was found that the most of trends were similar for both the case but the concentrations were different because of some simplified assumptions were considered for simulation model. Since the control strategies are not applicable at this stage, the studies are focusing on different operating condition towards the production of hydrogen along the stream. Steam to biomass ratio, temperature, and pressure are potential parameters to acquire higher production of hydrogen.

Result shows three reactors converting the biomass in producing hydrogen and other gasses. These reactors using gasification reaction equations to produce hydrogen and water key-in into the simulator. Due to gasification process favors endothermic reaction, high temperature is needed in operation condition. In this simulation, temperature for gasifier was set at 600 degree Celcius and kept constant throughout the simulation. Gasses composition throughout the reactor are changing accordingly, hydrogen as the main product of this production can be observe increase in composition throughout the reactor 1,2 and 3. This observation and simulation follows the reactions of gasification process to produce mainly hydrogen, carbon dioxide and carbon monoxide.

In figure 4.3 carbon monoxide and methane are observed throughout all reactors with different temperature, it shows reduction in composition for temperature in reactors from 550 to 675 degree Celsius then increase as the temperature of the reactor more than 700 degree Celsius. This is due to less air purged inside the reactors because of high combustion occurs with high temperature.

In figure 4.4, shows hydrogen produce higher when steam to biomass increased. This is due to gasification process requires abundant of water for the reaction to occur. Increasing steam to biomass ratio will definitely increase the production of hydrogen.

CHAPTER 5

CONCLUSION

To conclude, biomass gasification system has great potential to be optimized in various parameters. Starting from modelling of kinetic model and thermodynamic model to optimization of process control especially when dynamics behavior is also considered when modelling the system, this shown that understanding of dynamic behavior is crucial to optimize the system in highest efficiency level. Specifically for process control system, wide response of controller due to different signal given are studied in this project to understand the dynamic behavior so that in the future understanding of dynamics behavior of gasification system can be deeper and effort will be put to enhance the efficiency of the fluidized gasifier.

Aspen Plus software was used as modelling tool, a steady state model of biomass gasification system has completed. The model is validated by comparing the results of simulation with experiment’s result and the model is acceptable. There is a slight difference of the result; however, the error of difference is within acceptable range. Two variables are manipulated in this studies, temperature and steam to biomass ratio. It is found that the hydrogen production favours high temperature, however, the production decrease at 800^{o}C due to reverse carbonation reaction. The optimum temperature for fluidized bed gasifier is 675 ^{o}C where the production of hydrogen is 82.68%. For S/B Ratio, the production of hydrogen increased as the ratio increase. When S/B ratio is at 2.0, the percentage of hydrogen production increases 43.7%. This shows that hydrogen production favours S/B ratio. The effect of hydrogen production in temperature and steam to biomass ratio has been studied. Thus, this objective is also achieved.

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