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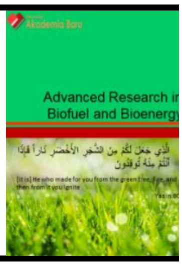

# Simulation Study of Biomass Gasification for Low Heating Value (LHV) Production

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**ABSTRACT**

Biomass gasification is a process of reacting biomass with the gasification agent in order to produce syngas. The gasification agents include steam, air, carbon dioxide and many more. The production of syngas is affected by temperature and pressure. Aspen Plus software is used to carry out the simulation study on the effect of temperature and pressure on the syngas composition. The syngas composition affects the Lower Heating Value (LHV) production which is used in internal combustion engine. From the simulation, the increase in temperature leads to the increase in LHV production as more hydrogen and carbon monoxide gas are produced. However, the increase in pressure leads to the decreasing in LHV production as more hydrogen and carbon monoxide gas are produced. Higher temperature favors endothermic reaction and higher pressure favors exothermic reaction. Therefore, suitable gasification operation conditions are at low pressure and high temperature.

***Keywords:***
Simulation; biomass; gasification; syngas
LHV

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## 1. Introduction

The project is about investigating the gasification system focusing on doing simulation with a steady state reaction. The overall system is biomass gasification system. Biomass gasification process is defined as a process of converting biomass which is the source of carbonaceous fuel into a gas product. The gas product is useful as it has a heat value which can be utilized as synthesis gas or fuel gas. The process involves the modification of the chemical structure of the biomass with the aid of a very high temperature. With the aid of the gasification agent, the biomass fed into the feeding stream can be converted into the gas product in a short period with different heterogeneous and homogenous reactions. The result of gasification process is the production of various gases, which are carbon dioxide ($CO_2$), carbon monoxide (CO), hydrogen ($H_2$), methane ($CH_4$), water and hydrocarbons. However, there are several contaminants which are still exist in the entire process. The contaminants include small particles of carbon matter, tar and ashes [1].

The fuel produced from the conversion of biomass can be used in many applications. The gas produced can be used in electric energy generation in engines, furnaces and gas turbines. On the other hand, the gas produced can be used in production of other various chemicals such as methanol,

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ammonia, methyl formate and other chemicals [1]. The advantage of utilizing biomass is it is a type of renewable energy in which it can be replenished. The importance of the project is to identify the most suitable condition to produce fuel through gasification process. With reference to several literature reviews, temperature, pressure and air flow rate affect the produced gas composition [2]. Therefore, several factors need to be taken into considerations in order to obtain gas fuel efficiently.

## 2. Methodology

### *2.1 Biomass Characterization*

Oil palm kernel shell is used as fuel or biomass in the gasifier to produce syngas. The kernel shell undergoes drying process and proceeds to the nut cracking process. Due to the dried kernel shell's high grade solid, high calorific value, low ash and low sulphur content, it is considered as in pellet form. The calorific value for dried kernel shell is 20100 kJ/kg. The yield of syngas can be determined from the composition of the biomass. Table 1 shows the chemical properties of palm kernel shell [3].

**Table 1**
Chemical properties of the palm kernel shell [3]

| Components | Ultimate analysis (wt% dry basis) |
|---|---|
| Carbon | 51.63 |
| Hydrogen | 5.52 |
| Nitrogen | 1.89 |
| Sulfur | 0.05 |
| Oxygen | 40.91 |

Components of the dried kernel shell listed in Table 1 will be specified further in the simulation.

### *2.2 Gasification Process*

According to Pandey *et al*., [4], gasification is a thermochemical process. It occurs when fuel and gasification agent such as steam, carbon dioxide, air or supercritical water (steam) react together and forming syngas. In gasification, there are five processes involved. These processes occur at various temperature.

Different biomass has different moisture level. Due to the water content inside the biomass, it is inefficient for syngas production. Therefore, the purpose of the first process which is the drying process is to remove all the water content. The ranging process temperature for drying process is in between 100 to 150 °C [5].

The second process in the gasification system is pyrolysis. In the absence of any air, biomass is heated at a high temperature ranging from 200 to 500 °C. The purpose of heating the biomass in absence of air is to turn biomass from solid into liquid form. In this process, there is a slight chance of decomposition of volatile component of the biomass. However, the amount of the decomposition of the volatile component are very small. The biomass solid transformed into liquid state is known as char. Due to the pyrolysis process, the fixed carbon-to-carbon chains are the only thing remains in char [6].

The next process involved in the gasification system is the cracking process. Throughout the cracking process, the large complex molecules from pyrolysis process such as tar is broken into lighter gases due to the exposure of heat. This is very important in the production of clean gas. If the cracking process is not included, the tar gases condense and forms sticky tar which have the tendency of fouling the valves of the engine. On the other hand, the cracking process is also important in ensuring the proper combustion. A complete combustion occurs when the combustible gases mix with oxygen thoroughly [7].

The final process involved in the gasification system is the reduction process. In reduction process, the oxygen atoms from the hydrocarbon molecules are stripped off. When oxygen atoms have been stripped off, the combustible gases which is used in the internal engines are formed. Reduction in this case is an opposite reaction of the combustion process.

### *2.3 Gasification Reaction*

During the gasification process, char undergoes multiple reactions. Due to this reaction, several gases are produced inside the system. Some of these gases are contributing to fuel production while some gases are not used in fuel production. According to National Academic Press [8], there are two types of reactions involved in the gasification system. They are exothermic reactions and endothermic reactions. The major reactions involved in the gasification process are listed below.

Exothermic reactions:

| | |
|---|---|
| Combustion | char + $O_2 \rightarrow CO_2$ |
| Partial Oxidation | char + $O_2 \rightarrow CO$ |
| Methanation | char + $H_2 \rightarrow CH_4$ |
| Water-Gas Shift | $CO + H_2O \rightarrow CO_2 + H_2$ |
| CO Methanation | $CO + 3H_2 \rightarrow CH_4 + H_2O$ |

Endothermic reactions:

| | |
|---|---|
| Steam-Carbon reaction | char + $O_2 \rightarrow CO + H_2$ |
| Boudouard reaction | char + $CO_2 \rightarrow 2CO$ |

Due to these reactions, the gases produced are carbon dioxide, carbon monoxide, methane and hydrogen.

### *2.4 Aspen Plus Simulation*

During the simulation, the physical controller in the steady state system will not appear. However, the system is being fixed or manipulated in the design specification option. With design specification, the user is able to define the value of calculated flow sheet quantity to a certain value. This is to ensure that the objective is accomplished by changing the specified input variable. The steps of using design specifications are measured variables are identified, the objective function and target are specified, the tolerance for the objective function is set, the manipulated variables (sensitivity analysis) are identified and the range of manipulated variable is specified. The flow sheet of the simulation is shown in Figure 1.

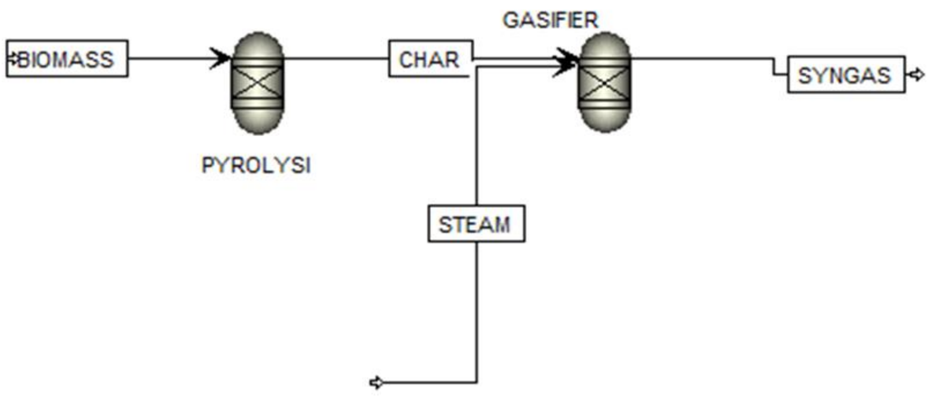


**Fig. 1.** Flow sheet of the simulation

With reference to the Figure 1, the types of reactor used for both PYROLYSI and GASIFIER in the simulation are RGIBBS. It is much relevant to use as the fraction of the feeds and the fraction of products are unidentified.

*2.5 Pyrolysis Simulation*

During the simulation for pyrolysis process, several assumptions are made and been considered. The assumptions made during the simulation are there is no heat loss to the surrounding of the system, there is no gases escape out from the system, the temperature set inside the pyrolysis system does not varies and the biomass entering the system are assumed to have the same shape and same properties.

The biomass entering the pyrolysis system is defined as non-conventional. The component attributes of the biomass is set in terms of PROXANAL and ULTANAL. Figure 2 shows the attributes set for the biomass (palm oil kernel).

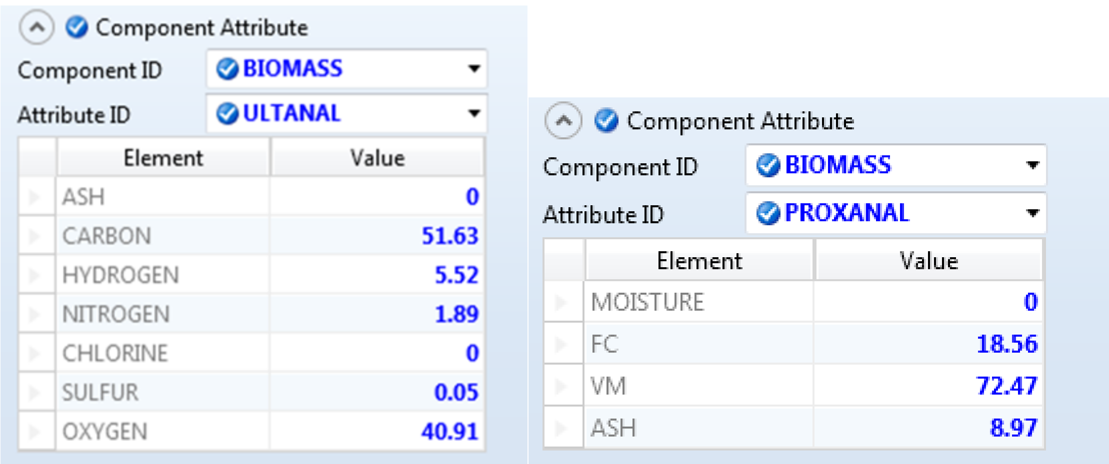


**Fig. 2.** Attributes set for biomass (palm oil kernel)

The state variables entering the system is set as shown in Figure 3.

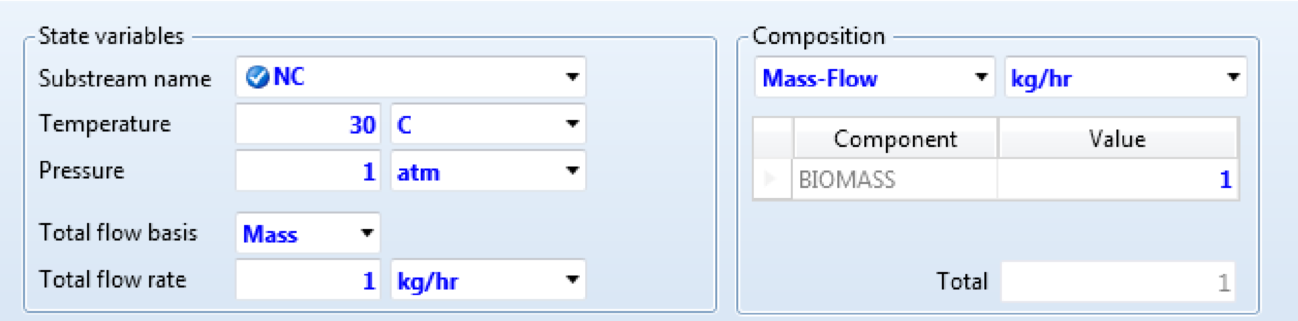


**Fig. 3.** Parameters set in the inlet stream

Based on Figure 3, the temperature and pressure of biomass entering the system is 30 °C and 1 atm respectively. The biomass enters the system on the basis of 1 kg/hr. However, the operating temperature of the system is set to 300 °C.

### *2.6 Biomass Gasification Simulation*

During the simulation for biomass gasification, several assumptions are made and been considered. The assumptions made during the simulation are the process conducted is in steady state and isothermal, there is no heat loss to the surrounding of the system, the temperature set inside the gasification system does not varies, the char produced entering the gasification system consists of only carbon, the gases produced at the end of gasification system are uniformly distributed and due to the high operating temperature, water (steam) entering and formed during the reaction are in vapor phase and not in liquid phase. The operating temperature and pressure for the gasifier is varied from 400 to 1500 °C and 1 to 10 bar respectively.

### *2.7 Lower Heating Value (LHV)*

Lower Heating Value (LHV) is commonly used in identifying the thermal efficiencies of the fuel. It is used to quote efficiencies based on the biomass fuel. The assumption made in identifying the LHV is that the water produced in the system via reaction remains in vapor state. The temperature involved in the system is usually several hundred degrees [8]. In gasification process, identifying LHV is much reliable as the temperature is ranging between 300 to 1400 °C and the water formed is always in vapor form.

In order to calculate the amount LHV produced for each of the sensitivity analysis, the mole fraction of certain gases need to be identified. The mole fraction of gases needed are mole fraction of carbon monoxide, methane and hydrogen. The formula for calculating the mole fraction are as listed below:

$$X_{CO} = \frac{mole\ of\ CO}{total\ mole\ of\ syngas}$$

$$X_{CH4} = \frac{mole\ of\ CH4}{total\ mole\ of\ syngas}$$

$$X_{H2} = \frac{mole\ of\ H2}{total\ mole\ of\ syngas}$$

After identifying the mole fraction for each of these gases, LHV is calculated based on the following formula:

$$LHV = (10110 * X_{CO} + 119494 * X_{H2} + 49915 * X_{CH4})\ kJ/kg$$

From the formula listed above, $X_{CO}$, $X_{H2}$, and $X_{CH4}$ represents the mole fraction of the produced gas.

## 3. Results

### *3.1 Pyrolysis Simulation Result*

According to the result obtained in Figure 4, it is found that the possible gases product of pyrolysis from decomposition of biomass are carbon monoxide, carbon dioxide, methane, acetylene, ethylene and hydrogen sulfide. The composition of these produced gases is very small. Thus, the simulation gives a result of 0 kg/hr for each of these gases which are considered negligible. As expected, there will be no reaction occured during the pyrolysis process. The purpose of the pyrolysis is to transform solid biomass into liquid char which is supplied directly into the gasification system. Therefore, it can be explained that the biomass entering and exiting the pyrolysis process are similar.

| − Mass Flows | kg/hr | 1 | 1 |
|---|---|---|---|
| CO | kg/hr | 0 | 0 |
| CO2 | kg/hr | 0 | 0 |
| CH4 | kg/hr | 0 | 0 |
| C2H2 | kg/hr | 0 | 0 |
| C2H4 | kg/hr | 0 | 0 |
| H2S | kg/hr | 0 | 0 |
| BIOMASS | kg/hr | 1 | 1 |

**Fig. 4.** Possible products from the pyrolysis process

### *3.2 Gasification Temperature*

According to the result obtained in Figure 5, it is observed that the temperature affects the amount of syngas compositions significantly. The amount of carbon monoxide and hydrogen gas produced increase significantly from 300 °C to 900 °C and remain constant from 900 °C to 1400 °C. However, the amount of methane and carbon dioxide gases produced decrease significantly as the temperature increases from 300 °C to 900 °C and remain constant after 900 °C. As the temperature increases, products from endothermic reactions are more favored compared to the products from the exothermic reactions. Endothermic reactions such as steam carbon reaction and Boudouard reaction are more favored compared to the combustion, partial oxidation, methanation, water-gas shift and carbon monoxide methanation which are exothermic reactions.

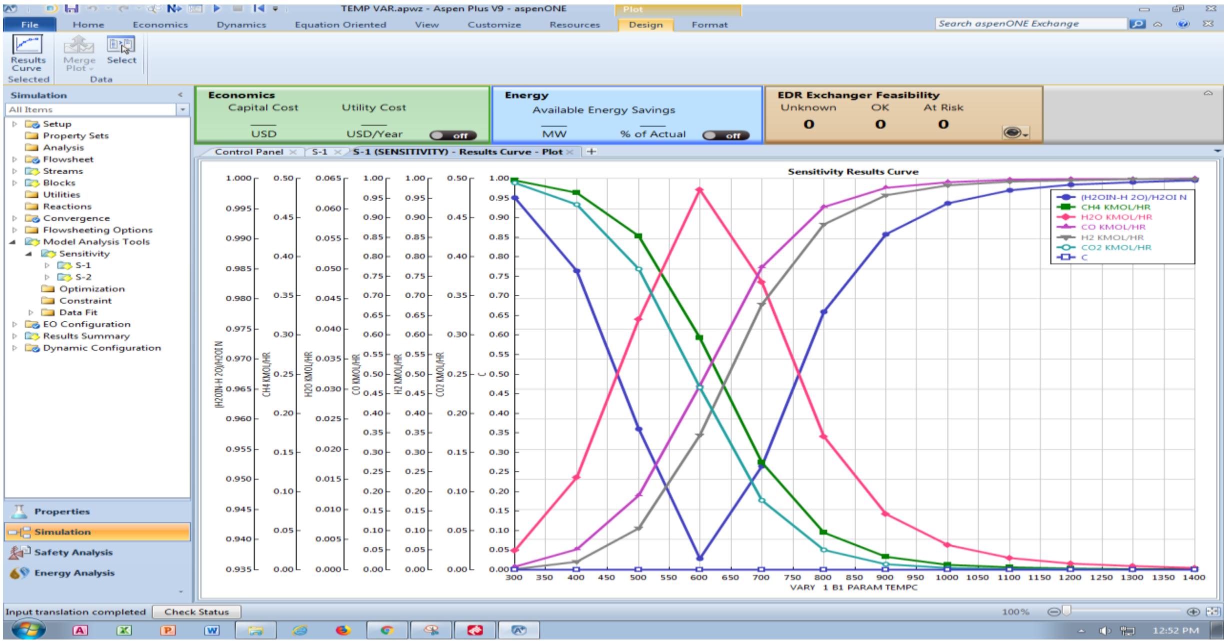


**Fig. 5.** Graph of gas composition versus temperature variation

### *3.3 Gasification Pressure*

According to the result obtained in Figure 6, it is observed that the pressure affects the amount of syngas compositions but not as significant as temperature variations. The amount of carbon monoxide and hydrogen gas produced are decreasing from 1 to 10 bar and remain constant afterwards. However, the amount of methane and carbon dioxide gases produced increase as the pressure increases from 1 to 10 bar and remain constant afterwards. As temperature increases, products from exothermic reactions are more favored compared to the products from the exothermic reactions.

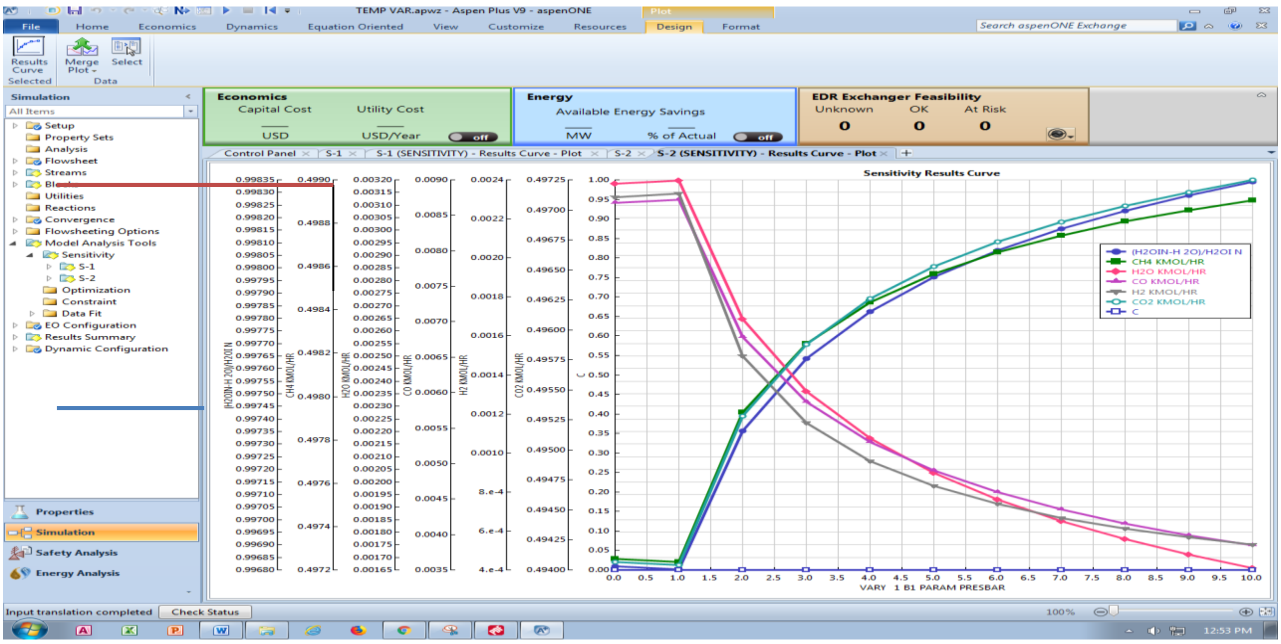


**Fig. 6.** Graph of gas compositions versus pressure variations

*3.4 Lower Heating Value of the Syngas*

By referring to the result obtained from Figure 7, the amount of LHV produced increase as the temperature during the gasification process is increasing. The amount of hydrogen and carbon monoxide gas produced are higher. The gases that contribute in LHV production are hydrogen and carbon monoxide.

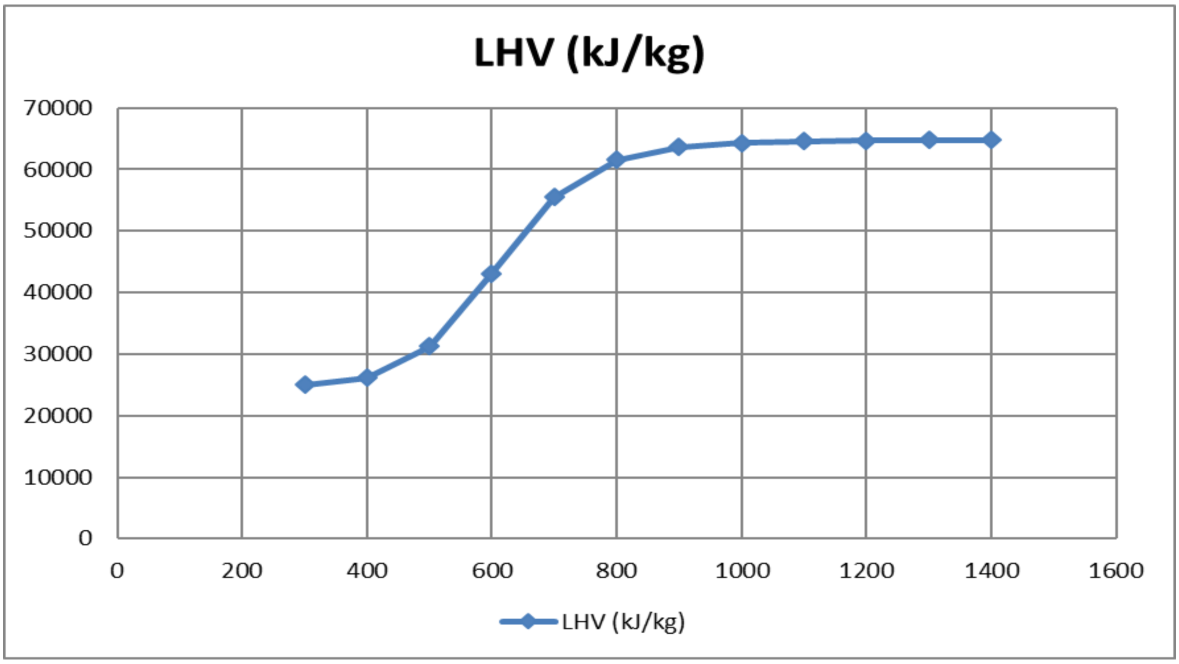


**Fig. 7.** Graph of LHV versus temperature variations

By referring to the result obtained from Figure 8, the amount of LHV produced are decreasing as the pressure during the gasification process is increasing. The amount of hydrogen gas and carbon monoxide gas produced are lesser.

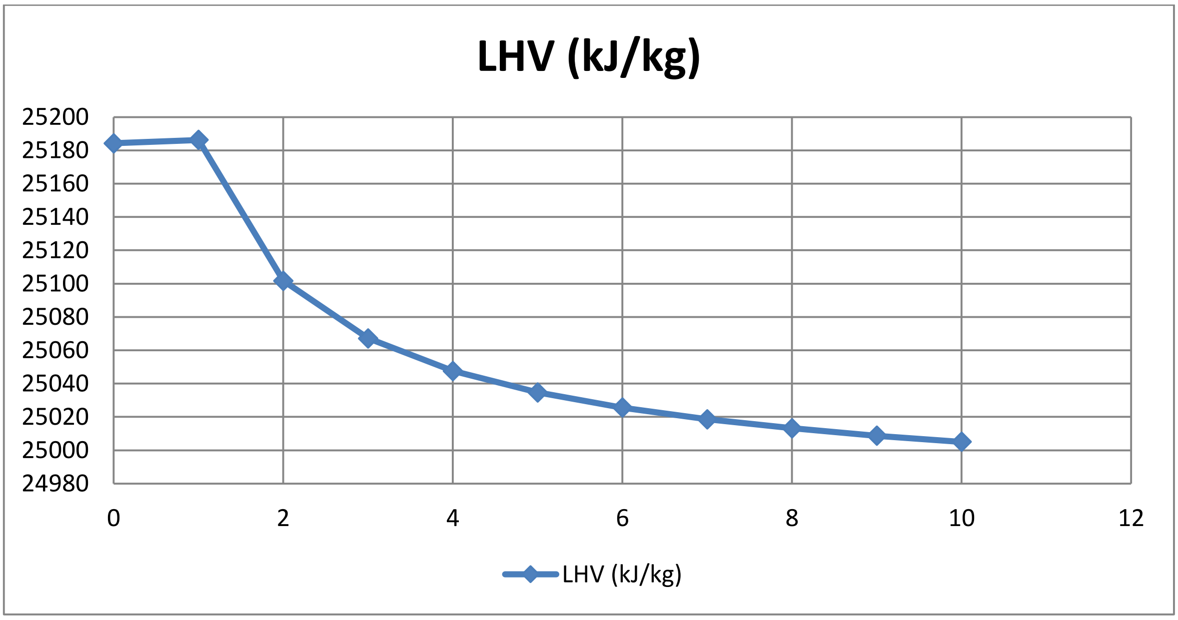


**Fig. 8.** Graph of LHV versus pressure variations

## 4. Conclusions

There is a great potential to optimize the biomass gasification system by varying multiple parameters. In completing the steady state model of biomass gasification system simulation, Aspen Plus software is used as the modelling tool. During the simulation, the two variables that are manipulated in this study are temperature and pressure. It is observed that hydrogen and carbon monoxide productions which involve in LHV production requires these temperature and lower pressure. The optimum temperature for the gasification process of the palm oil kernel is 900 °C in which the carbon monoxide produced is 49.99% and hydrogen gas produced is 49.87%. The optimum pressure for the gasification process of the palm oil kernel is 1 bar in which the carbon monoxide produced is 8.70% and hydrogen gas produced is 2.3%. The effect of temperature and pressure on LHV production has been studied.

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