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Design of Liquefaction Process of Biogas using Aspen HYSYS Simulation

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ABSTRACT

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The liquefaction of biogas appears to be an appropriate solution in cases where logistics constraints arise due to the absence of a transportation network. In liquid form, biomethane is easy to transport to its point of use. Aspen HYSYS, computer-aided process design programs, widely used in chemical and thermodynamic process industries, which has built-in process models that can effectively simulate the liquefaction process. In this study liquefaction process of biogas was simulated in Aspen HYSYS with the aim to assess the technology using cryogenic process to liquefy the biogas and obtain the liquefied biomethane and CO₂ as a by-product through the simulation results. The parameters such as biogas feed, temperature and pressure are obtained from the case study from Havys Biogas Power Plant owned by Cenergi Sdn. Bhd. Hence, with a working principle of cryogenic process, a design of the process of liquefaction of biogas was simulated in Aspen HYSYS simulation environment where it consists of three stages, which are pre-cooling stage, liquefaction stage and sub-cooling stage. As a result, with a biogas feed of 1,500 m³/h consists of 60% CH₄ and 40% CO₂ at 200 kPa and 35°C, liquefied biomethane were obtained from the design of the simulation with a purity of 99% and liquid CO₂ was also obtained as a by-product of the liquefaction process.

Keywords:

Biogas, liquefaction, cryogenic, Aspen HYSYS

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1. Introduction

Malaysia has a huge amount of potential for power generation when it comes to the gas industry. Imbued with a wealth of natural gas that can be exported and utilized in domestic power plants, Malaysia also has a flourishing palm oil industry, which allows the potential for co-generation, biogas and bio-fuel applications [1]. Besides, the increasing trend of oil and natural gas prices and new targets for renewable fuels quotes lead to an increasing interest in the use of biogas as an alternative source of energy.

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Biogas is a gas mixture obtained from the decomposition of organic matter by bacteria in anaerobic conditions. The gas mixture consists of CH₄, CO₂, H₂, N₂, H₂O, and H₂S [2]. The proportion of these gases can be seen in the Table 1. Methane (CH₄) is the main component in the fuel, and it is flammable. Methane content in biogas is over 50 percent. The raw biogas is purified to prevent corrosion and mechanical wear of the equipment in which it is used. For some applications demanding a high energy content gas, namely vehicle fuels and injection in the natural gas grid, the biogas must be upgraded into biomethane [3]. It means that the concentration of methane in the biogas must be increased by removing carbon dioxide. However, for certain applications, biogas must be liquefied.

Table 1
 Properties of natural gas, raw biogas and biomethane [4]

Gas composition	Biogas	Biomethane	Natural Gas
Methane	50-75%	94-99.9%	93-98%
Carbon Dioxide	25-45%	0.1-4%	1%
Nitrogen	<2%	<3%	1%
Oxygen	<2%	<1%	-
Hydrogen	<1%	Traces	-
Hydrogen Sulphide	20 – 20,000 ppm	<10 ppm	-
Ammonia	Traces	Traces	-
Ethane	-	-	<3%
Propane	-	-	<2%
Siloxane	Traces	-	-
Water	2-7%	-	-

In this study, due to the fact that conducting the experiment on liquefaction process of biogas is expensive, simulations process is used to design the liquefaction process of biogas close to the real plant. Process simulation is a widely used technique in the design, analysis, and optimization of process plants. Aspen HYSYS can be used to simulate most cryogenic liquefaction processes. In cryogenic process, the process is based on separating mixture components according to their different relative volatilities or boiling points where methane and CO₂ are at -162 °C and -80 °C. Nitrogen with boiling point of -197 °C are used as a coolant to cool the biogas first before being separated. Cryogenic technology has been seen as the most efficient method for liquefying the biogas.

Biogas is considered as renewable gases and the combustion of the biomass has little effect upon GHGs concentrations in the atmosphere [5]. If the biogas is being utilized to other applications, the negative of GHGs emission can be easily realized. The release of biogas which mainly comprises of methane and CO₂ to the atmosphere is such a waste hence it can be used for utilization in the energy industry. A cleaner energy future depends on the development of alternative energy technologies to meet the world growing energy needs. Figure 1 illustrates data and scale of reductions of GHG emissions from passenger cars when compared with fossil fuel alternatives. Based on the figure, production of biogas from waste from all sources which are agricultural, forestry, industrial and municipal, for the production of combined heat and power is a very effective GHG mitigation measure.

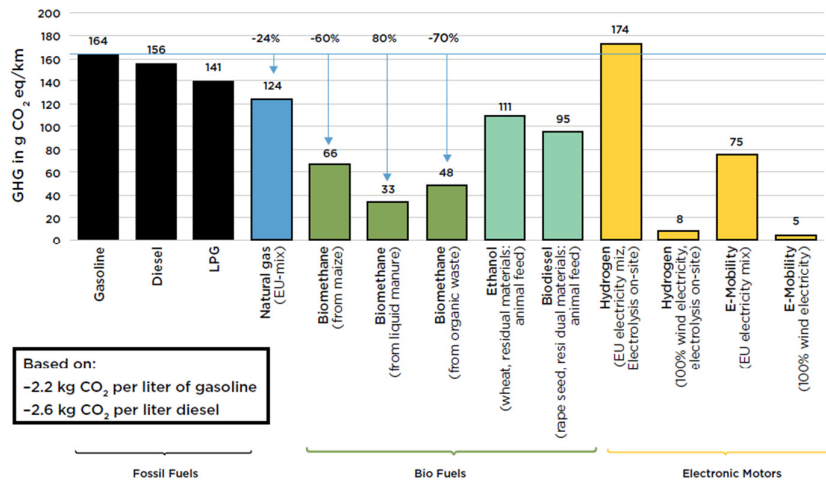


Fig. 1. Comparative GHG emissions from passenger cars using different fuels [5]

Currently, most of the studies focus on how to improve the efficiency of biogas upgrading [6]. There has not been a comprehensive analysis from the perspective of the liquefaction of the biogas process. Therefore, to bridge the knowledge gap, this study aims at assessing the aforementioned technologies that is by using cryogenic technology to liquefy the biogas to obtain the liquefied biomethane and liquid CO₂ as a byproduct through the simulation results. This paper will shows the design of the liquefaction process of biogas using Aspen HYSYS simulator to obtain the liquified biomethane and liquid CO₂.

The liquefaction of biomethane appears to be an appropriate solution in cases where logistics constraints arise due to the absence of a transportation network. In liquid form, biomethane is easy to transport to its point of use. The advantages of the liquefaction of biomethane process are when the energy consumption is optimal, the process is reliable and efficient, and the technology is well understood and well managed [7]. When biogas is condensed to a liquid by cooling it to about -162°C. This process reduces its volume by a factor of more than 600 [8]. Thus, this will allow the liquified biomethane to be shipped safely and efficiently.

2. Methodology

Table 2 represent the parameters used for the simulation of liquefaction process.

Table 2
The parameters specified for biogas feed stream

Parameter	Value	References
Feed	1500 m ³ /h (63.44 kgmol/h) of raw biogas	Case study
Pressure	200 kPa	[9]
Temperature	35 °C	
Composition		
Methane	60 %	
Carbon dioxide	40 %	[9]

Aspen HYSYS v9 software was used for the simulation of liquefaction of biogas unit. Because, in this simulation available components are hydrocarbon and nonpolar, Peng Robinson equation of state is used for thermodynamic calculations. The design of liquefaction process is based on the case of nitrogen rejection using cryogenic distillation column, which is available in Aspen HYSYS library. Modifications on the case are being done based on the literature review to achieve the objective of this study. It consists of two compressors, three coolers, a LNG exchanger, a pump, and a distillation column.

3. Results and Discussion

As a result, the design of a liquefaction process of biogas by using the Aspen HYSYS simulation is shown in the simulation environment in Figure 2. Figure 2 describes the liquefaction process of biogas. The flowsheet in Aspen HYSYS shows the various components and the material streams needed to bring about the liquefaction of the biogas.

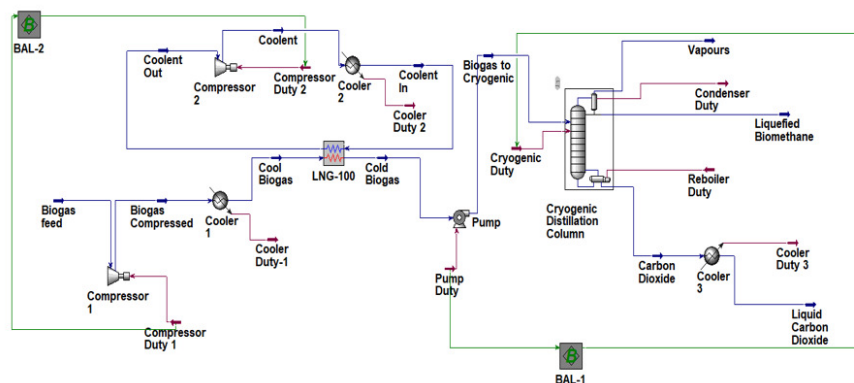


Fig. 2. Design of a liquefaction process of biogas in Aspen HYSYS

For production of liquefied biomethane, the biogas is cooled down to temperature of $-162\text{ }^{\circ}\text{C}$. In this case, the gas turned to an odourless and transparent liquid. In this study, nitrogen is used as refrigerants for the liquefaction of biogas due to the boiling points of nitrogen which is at $-197\text{ }^{\circ}\text{C}$. Based on Figure 2, before entering the cryogenic distillation column, which is the important unit operation for liquefying biogas, the biogas need to be cooled first to avoid freezing in the cooling step. The biogas feed at the temperature of $35\text{ }^{\circ}\text{C}$ and pressure at 200 kPa is compressed to 2 MPa and cooled down to temperature of $-48\text{ }^{\circ}\text{C}$ to freeze out of possible impurities. LNG exchanger is used for cooling the cool biogas to $-162\text{ }^{\circ}\text{C}$. Three stage exchangers used for this purpose. The first stage which is precooling stage, is as mentioned before where the biogas is cooled down to $-48\text{ }^{\circ}\text{C}$. In second stage which is liquefaction stage, biogas is cooled to $-120\text{ }^{\circ}\text{C}$. Finally, in the third stage which is sub cooling stage, the biogas is cooled down to $-162\text{ }^{\circ}\text{C}$ to obtain liquefied biomethane.

In precooling stage, the cooler has been used to decrease the temperature of the biogas. Inlet biogas feed is in temperature $35\text{ }^{\circ}\text{C}$ and the pressure of 200 kPa . In this stage, the temperature is reduced to $-40\text{ }^{\circ}\text{C}$ after being compressed. In liquefaction stage, liquified natural gas (LNG) exchanger with two streams is used. The first stream is a nitrogen which used as a refrigerant with the temperature set at $-130\text{ }^{\circ}\text{C}$. This stream is a part of stage which includes a compressor and cooler. In this stage, the temperature of biogas is reduced to $-120\text{ }^{\circ}\text{C}$. The temperature cannot be reduced to

lower than the stated temperature using nitrogen. The second stream is “cool biogas” cooled in the LNG exchanger for using in third exchanger which is sub cooling stage as a “cold biogas”. In this stage also, the first stream which is “coolant in” enters to the compressor for increasing its pressure, then it enters into a cooler for the reduction of its temperature. At last, it enters back into the LNG exchanger.

In the third stage, the cold biogas enters pump for increasing its pressure, then it enters the cryogenic distillation column. The cryogenic distillation process is the important process for the overall process because this process performs the actual liquefaction of biogas into liquefied biomethane. The operation in the column at one (1) bar is a good compromise for an acceptable low temperature of the liquid. The heat duties of the reboiler of the low-pressure column and heat duties of the condenser of the high-pressure column are different to obtain two various products which is liquid biomethane at high pressure and solid carbon dioxide at low pressure. At the end of the process, liquid biomethane is obtained by condensing the biogas to $-162\text{ }^{\circ}\text{C}$. The carbon dioxide will enter the reboiler and left the distillation column as liquid carbon dioxide.

The simulated data summary is extracted from Aspen HYSYS simulation shown in Table 3. Based on the data, it shows that the liquefied biomethane are obtained with purity of 99 per cent and 99 per cent of liquid CO_2 as a byproduct of this process. Hence, based on the literature study, the percentage of the purity of the methane are following the requirement for the biogas to be used as a vehicle fuel. From the table, liquefied biomethane are obtained at temperature of $-161.719\text{ }^{\circ}\text{C}$ and liquid CO_2 also obtained with the temperature of $-56.6\text{ }^{\circ}\text{C}$ where at this temperature, both gases are in the liquid form. In the liquid form, both gases can be stored and transported easily to minimize the cost of storage and transportation.

Table 3
Summary of the data extracted from Aspen HYSYS simulator

Name	Liquefied Biomethane	Liquid Carbon Dioxide
Vapour	0	0
Temperature [$^{\circ}\text{C}$]	-161.7190	-56.6000
Pressure [kPa]	100	2620
Molar Flow [kgmole/h]	51.1880	12.2520
Mass Flow [kg/h]	825.4980	539.1340
Mole fraction [%]		
Methane	0.9970	0.0002
Carbon dioxide	0.0030	0.9998
Molar Enthalpy [kJ/kgmole]	-90489.0800	-410169.2400
Molar Entropy [kJ/kgmole $^{\circ}\text{C}$]	76.3883	85.1360

4. Conclusions

Production of biogas from waste, which otherwise would have decomposed and released both methane and CO_2 to the atmosphere, appears an uncontroversial, low cost route to reduce carbon emissions. Liquefied biomethane through refinement process and cryogenic liquefaction process has many advantages that include improvement in transportability and storability. Liquefied biomethane are obtained through the design with a purity of 99% and liquid carbon dioxide also obtained as a byproduct of the liquefaction process. The results obtained from simulation will helps to carry out

experiments in laboratory at optimum condition and in large scale of production of liquefied biomethane can be made.

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