



## Design of Liquefaction Process of Biogas with Aspen HYSYS Simulation

Open  
Access

Nurjehan Ezzatul Ahmad<sup>1</sup>, Maizirwan Mel<sup>1,\*</sup>

<sup>1</sup> Department of Biotechnology Engineering, Faculty of Engineering, International Islamic University, Malaysia (IIUM),  
PO Box 50278, Kuala Lumpur, Malaysia

### ARTICLE INFO

### ABSTRACT

#### Article history:

Received 21 June 2018

Received in revised form 5 August 2018

Accepted 2 September 2018

Available online 11 September 2018

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. This study aims to design the liquefaction process of biogas with the help of the simulation tool of Aspen HYSYS. This study also aims at assessing the aforementioned technologies, which is by using cryogenic technology to liquefy the biogas to obtain the liquefied biomethane and liquid CO<sub>2</sub> 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 1500 m<sup>3</sup>/h consists of 60% CH<sub>4</sub> and 40% CO<sub>2</sub> at 200 kPa and 35°C, liquefied biomethane are obtained from the design of the simulation with a purity of 99% and liquid CO<sub>2</sub> also obtained as a by-product of the liquefaction process.

#### Keywords:

Biogas, Liquefaction, Cryogenic, Aspen  
HYSYS

Copyright © 2018 PENERBIT AKADEMIA BARU - All rights reserved

## 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.

\* Corresponding author.

E-mail address: [maizirwan@iium.edu.my](mailto:maizirwan@iium.edu.my) (Maizirwan Mel)

Biogas is a gas mixture obtained from the decomposition of organic matter by bacteria in anaerobic conditions. The gas mixture consists of CH<sub>4</sub>, CO<sub>2</sub>, H<sub>2</sub>, N<sub>2</sub>, H<sub>2</sub>O, and H<sub>2</sub>S [2]. The proportion of these gases can be seen in the Table 1 below. Methane (CH<sub>4</sub>) 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 CO<sub>2</sub> 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. 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 CO<sub>2</sub> 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 's 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.

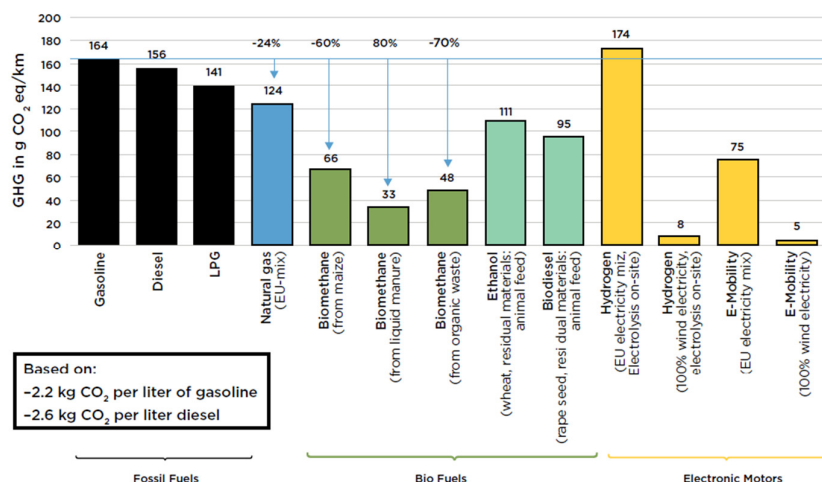


Fig. 1. Comparative GHG emissions from passenger cars using different fuels [5]

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 which is by using cryogenic technology to liquefy the biogas to obtain the liquefied biomethane and liquid CO<sub>2</sub> as a byproduct through the simulation results. This paper will shows the design of the liquefaction process of biogas using Aspen HYSYS simulator.

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 liquefied biomethane to be shipped safely and efficiently.

## 2. Methodology

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

**Table 2**  
The parameters specified for biogas feed stream

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

Aspen HYSYS 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

### 3. Result

The diagram illustrates a cryogenic distillation system for biogas liquefaction. The process begins with a 'Biogas feed' entering 'Compressor 1'. The output, 'Biogas Compressed', goes to 'Cooler 1'. The cooled biogas then passes through an 'LNG-100' heat exchanger, which pre-cools the feed. The pre-cooled biogas is then compressed by 'Compressor 2' and cooled by 'Cooler 2' before entering the 'Cryogenic Distillation Column'. The column separates the feed into 'Vapours' at the top and 'Liquid Carbon Dioxide' at the bottom. The vapours pass through a 'Condenser' and a 'Reboiler' before being liquefied into 'Liquefied Biomethane'. The liquid carbon dioxide is cooled by 'Cooler 3' and then pumped by 'Pump 1' to 'Compressor 3', which feeds back into 'Compressor 1'. The system also includes a 'Cryogenic Duty' stream and a 'Pump Duty' stream, which are managed by 'BAL-1' and 'BAL-2' control units. The overall process is designed to efficiently liquefy biogas for storage and transport.

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.

12

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  $\text{CO}_2$  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  $\text{CO}_2$  also obtained with the temperature of  $-56.6\text{ }^{\circ}\text{C}$  where at this temperature, both gases are in the liquid form.

**Table 3**

Summary of the data extracted from Aspen HYSYS simulator

Name	Liquefied Biomethane	Liquid Carbon Dioxide
Vapour	0	0
Temperature [ $^{\circ}\text{C}$ ]	-161.719	-56.6
Pressure [kPa]	100	2620
Molar Flow [kgmole/h]	51.188	12.252
Mass Flow [kg/h]	825.498	825.498
Mole fraction [%]		
Methane	0.997	0.0002
Carbon dioxide	0.003	0.9998
Molar Enthalpy [kJ/kgmole]	-90489.08	-410169.24
Molar Entropy [kJ/kgmole $^{\circ}\text{C}$ ]	76.3883	85.136

## 4. Conclusions

Production of biogas from waste, which otherwise would have decomposed and released both methane and  $\text{CO}_2$  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 lab at optimum condition and in large scale of production of liquefied biomethane can be made.

## References

- [1] Lattermann, R. (2013). Pioneering Gas Technology in Malaysia, 30–32.

- [2] Khan, Imran Ullah, Mohd Hafiz Dzarfan Othman, Haslenda Hashim, Takeshi Matsuura, A. F. Ismail, M. Rezaei-DashtArzhandi, and I. Wan Azelee. "Biogas as a renewable energy fuel—a review of biogas upgrading, utilisation and storage." *Energy Conversion and Management* 150 (2017): 277-294.
- [3] Petersson, Anneli, and Arthur WellinGer. "Biogas upgrading technologies—developments and innovations." *IEA bioenergy* 20 (2009): 1-19.
- [4] DOSH. (2016). Guidelines on Occupational Safety and Health in Construction, Operation and Maintenance of Biogas Plant, (i), 1–76.
- [5] Union, T. E., States, T. U., & Lambert, M. (2017). Biogas: A significant contribution to decarbonising gas markets? The Oxford Institute for Energy Studies, (June), 1–15.
- [6] Li, Hailong, Yuting Tan, Mario Ditaranto, Jinying Yan, and Zhixin Yu. "Capturing CO<sub>2</sub> from biogas plants." *Energy Procedia* 114 (2017): 6030-6035.
- [7] Brynolf, Selma, Erik Fridell, and Karin Andersson. "Environmental assessment of marine fuels: liquefied natural gas, liquefied biogas, methanol and bio-methanol." *Journal of cleaner production* 74 (2014): 86-95.
- [8] Pellegrini, L. A., Guido, G. De, & Langé, S. (2017). Biogas to liquefied biomethane via cryogenic upgrading technologies. Renewable Energy. In S. A. Muyibi, H. Hazalilah, I. Irmayanti, and J. M. M. N. Megat. "Coagulation of river water with Moringa oleifera seeds and alum a comparative study," *Journal Institution of Engineers Malaysia* Vol.62 no, 2, 15-21, 2001.
- [9] Yousef, Ahmed MI, Yehia A. Eldrainy, Wael M. El-Maghlany, and Abdelhamid Attia. "Upgrading biogas by a low-temperature CO<sub>2</sub> removal technique." *Alexandria Engineering Journal* 55, no. 2 (2016): 1143-1150.