Dynamic Design Parameters of Liquifaction Biogas Process Simulation using Aspen Hysys

Engr. Nnadikwe Johnson[1], Engr. Ewelike Asterius[2], Emeribe Happiness Ebere[3], Samuel Dotse[4]

1. H.O.D in Department of Petroleum and Gas Engineering, Imo State University, Nigeria
2. H.O.D in Agricultural Engineering, Imo State University, Nigeria
3. Lecturer in Civil Engineering Department, Imo State University, Nigeria
4. Lecturer in School of Global Business and Economics HATOF Foundation CEO Ghana

ABSTRACT

The liquefaction of biogas looks to be a viable option in situations where logistics are hampered by a lack of a transportation network. Biomethane is straightforward to transport in liquid form to its final destination. Aspen HYSYS is a computer-aided process design program that has built-in process models that can effectively simulate the liquefaction process. It is widely used in the chemical and thermodynamic process industries. In this study, the liquefaction of biogas was simulated in Aspen HYSYS with the goal of evaluating the technique of using a cryogenic method to liquefy biogas and get liquefied biomethane and CO2 as a by-product. The characteristics such as biogas feed, temperature, and pressure were collected from a case study at Obinze Slaughter. ISN Biorenewable power plant. As a result, using the cryogenic process as a working concept, a design of the biogas liquefaction process was simulated in the Aspen HYSYS modeling environment, which consists of three stages: pre-cooling, liquefaction, and sub-cooling. As a consequence, with a biogas input of 1,500 m3/h containing 60% CH4 and 40% CO2 at 200 kPa and 35°C, liquefied biomethane with a purity of 99 percent was achieved from the simulation design, and liquid CO2 was acquired as a by-product of the liquefaction process.

***Keywords**: CO2, CH4, Biogas, Aspen Hysys, Simulation*

1. INTRODUCTION

When it comes to the gas business, Malaysia has a lot of potential for power generation. Malaysia has a thriving palm oil sector, which allows for co-generation, biogas, and biofuel applications [1]. It also has a wealth of natural gas that can be exported and used in domestic power plants. Furthermore, the rising trend in oil and natural gas prices, as well as new targets for renewable fuels quotes, have increased interest in biogas as an alternative energy source.

Biogas is a gas mixture produced by microorganisms decomposing organic materials in anaerobic circumstances. CH_4, CO_2, H, N_2, H_2O, and H_2S make up the gas mixture [2]. Table 1 shows the relative proportions of various gases. The main component of the fuel is methane (CH4), which is combustible. Biogas has a methane level of more than 50%. To prevent corrosion and mechanical wear of the equipment in which it is utilized, the raw biogas is cleaned. Biogas must be converted into biomethane for some uses that require a high energy content gas, such as automotive fuels and injection into the natural gas system [3]. It indicates that by removing carbon dioxide from the biogas, the concentration of methane in the gas must be increased. Biogas, on the other hand, must be liquefied for particular purposes.

Table 1

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

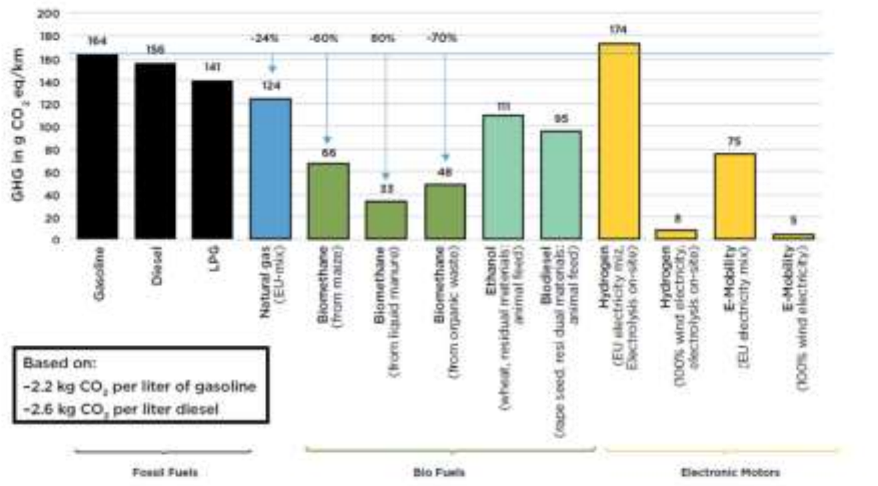
Gas composition	Biogas	Biomethane	Natural Gas
Methane	50-75%	94-99.9%	93-98%
Carbon Dioxide	25-45%	0.1-4%	1%
Nitrogen	<2%	<3%	1%
Oxygen	<2%	<1%	-
Hydrogen	<1%	Traces	-
Hydrogen Sulphide	20 – 20,000 ppm	<10 ppm	-
Ammonia	Traces	Traces	-
Ethane	-	-	<3%
Propane	-	-	<2%
Siloxane	Traces	-	-
Water	2-7%	-	-

Because doing an experiment on the liquefaction process of biogas is costly, simulations are utilized in this work to build a biogas liquefaction process that is as near to the real plant as possible. Process simulation is a popular method for designing, analyzing, and optimizing process plants. Most cryogenic liquefaction processes can be simulated using Aspen HYSYS. The cryogenic process works by separating mixture components based on their distinct relative volatilities or boiling points, which are -162 °C and -80 °C for methane and CO_2, respectively. The biogas is cooled first before being separated using nitrogen, which has a boiling point of -197 °C. Cryogenic technology has been seen as the most efficient method for liquefying the biogas.

Biogas is regarded as a renewable source of energy, and its combustion has negligible impact on GHG levels in the atmosphere [5]. If biogas is used for other purposes, the negative impact on GHG emissions is easily realized. Because the release of biogas, which primarily consists of methane and CO2, into the atmosphere is such a waste, it can be employed in the energy business. To fulfill the world's expanding energy needs, the development of alternative energy technologies is essential for a greener energy future. Figure 1 shows the facts and scale of GHG emission reductions from passenger cars against fossil fuel alternatives. Biogas generation from waste from all sources, including agricultural, forestry, industrial, and municipal waste, for the production of combined heat and power is a very effective GHG mitigation measure, according to the graph.

The majority of current research is on ways to improve the efficiency of biogas upgrading [6]. There hasn't been a thorough examination of the biogas liquefaction process. To fill the information gap, this study will use simulation findings to evaluate the aforementioned technologies, which include using cryogenic technology to liquefy biogas to create liquefied biomethane and liquid CO_2 as a byproduct. This paper will demonstrate how to construct a biogas liquefaction process using the Aspen HYSYS simulator to produce liquid biomethane and liquid CO_2.

In circumstances where logistics restrictions develop due to the lack of a transportation network, biomethane liquefaction looks to be an acceptable alternative. Biomethane is straightforward to transport in liquid form to its final destination. When the energy consumption is optimal, the process is dependable and efficient, and the technology is properly understood and managed, the liquefaction of biomethane process has several advantages [7]. When biogas is cooled to -162°C, it condenses into a liquid. This method reduces the volume by more than 600 times [8]. As a result, the liquefied biomethane may be transported safely and effectively.



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	Reference
Feed Pressure Temperature	1500m^3/h (63.44 kgmol/h) of raw biogas 200kPa 35^{o}C	Case study [9]
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.

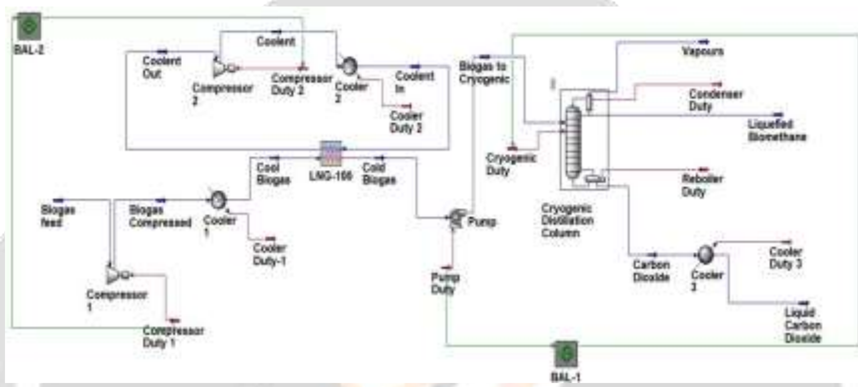


Fig. 2. Design of a liquefaction process of biogas in Aspen HYSYS

The biogas is cooled to a temperature of -162 °C in order to produce liquefied biomethane. In this example, the gas converted into a clear, odorless liquid. Because nitrogen has a boiling point of -197 °C, it is used as a refrigerant for the liquefaction of biogas in this study. Figure 2 shows that before entering the cryogenic distillation column, which is a critical unit operation for liquefying biogas, the biogas must first be chilled to avoid freezing during the cooling stage. The biogas input is compressed to 2 MPa and chilled to -48 °C to remove any possible pollutants at a temperature of 35 °C and a pressure of 200 kPa. The cold biogas is cooled to -162 °C using an LNG exchanger. This was accomplished using three step exchangers. As previously stated, the biogas is cooled to -48 °C in the first stage, which is known as precooling. Biogas is chilled to -120 °C in the second stage, which is the liquefaction stage. Finally, the biogas is cooled to -162 °C in the third stage, known as the sub cooling stage, to produce liquefied biomethane.

In precooling stage, the cooler has been used to decrease the temperature of the biogas. Inlet biogas feed is in temperature 35 °C and the pressure of 200 kPa. In this stage, the temperature is reduced to -40°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°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°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 °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 °C and liquid CO_2 also obtained with the temperature of -56.6 °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 [°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°C]	76.3883	85.1360

4. CONCLUSIONS

Biogas production from garbage, which would otherwise degrade and emit both methane and CO_2 into the atmosphere, appears to be an uncontroversial and low-cost method of reducing carbon emissions. The advantages of liquefied biomethane obtained through the refining and cryogenic liquefaction processes include improved transportability and storability. Through the design, 99 percent pure liquefied biomethane is obtained, as well as liquid carbon dioxide as a byproduct of the liquefaction process. The simulation results will aid in the conduct of research in the laboratory under ideal conditions, as well as the manufacture of liquefied biomethane on a wide scale.

ACKNOWLEDGEMENTS

The Author would like to thank Imo state university, software application laboratory, for Helpful advice and discussion

REFERENCES

[1] Lattermann, R. (2013). Pioneering Gas Technology in Malaysia, 30–32. Power Insider, Vol. 3 No. 3 (June).

[2] Ullah Khan, Imran, 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, no. 1 (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 Occuppational 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 CO2 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, 1–20.

[9] Yousef, Ahmed MI, Yehia A. Eldrainy, Wael M. El-Maghlany, and Abdelhamid Attia. "Upgrading biogas by a low-temperature CO2 removal technique." *Alexandria Engineering Journal* 55, no. 2 (2016): 1143-1150.