

**MODELLING A CRYOGENIC BIOGAS CONVERTING INTO LIQUIFIED BIOMETHANE BY HIGH PRESSURE AND LOW-PRESSURE COLUMN IN ASPEN HYSYS****Kishore B**Assistant Professor, Department of Chemical Engineering,  
Mahendra Engineering College, Mallasamudram, Namakkal, Tamil Nadu – 637503.**ABSTRACT**

Liquified Bio-Methane (LBM) from biogas producing two major intensive processes; upgrading to increase the methane concentration and refrigeration to liquefy the upgraded biogas. Absorbing method of LBM the temperature increase is associated with amine regeneration is in conflict with the cooling requirement of the subsequent liquefaction process. Hence, cryogenic biogas upgrading, integrated with liquefaction, has emerged as an interesting alternative. In this an extensive energy analysis was performed for comprehensive models of LBM production alternatives. These processes were modeled using Aspen HYSYS and optimized to minimize the energy use. The results indicate that the integrated cryogenic upgrading process is favorable in terms of both overall energy efficiency and product utilization. Moreover, the energy analysis implies that the liquefaction process accounts for the major part of the energy input to an LBM plant.

**Keywords:**

Aspen HYSYS, Liquified, Biomethane, Liquefaction, Refrigeration, Cryogenic, Upgrading

**1. INTRODUCTION**

The use of fossil fuels in the transportation sector has remained dominant although renewable energy sources being introduced in the energy market. According to a recent report from the Renewable Energy Policy Network for the 21st century, the global renewable share of total energy use was 20.5% in 2016. However, the permeation of renewable energy in different sectors is not identical; for instance: energy use in the transportation sector comprises 32% of the total energy use in the world, out of which renewable energies like biofuels and renewable electricity account for only 3.1% [1]. Lately, liquefied biomethane (LBM) from biogas has attracted much interest as an alternative fuel (International Energy Agency, 2017). Similar to liquefied natural gas (LNG), the energy density of LBM is about 21 MJ/L, which is approximately 2.4 times higher than that of compressed biomethane (Bio-CNG) (Arteconi et al., 2013). The higher energy density of LBM makes it feasible as long-distance transportation fuel. Currently, the global LBM production is limited to only 43,100 tonnes per annum, which is considerably lower than global trade of liquefied natural gas (LNG) with 293.1 million tonnes in 2017. However, it is estimated that demands for LBM will increase not only for the vehicle transportation sector, but also in maritime transport over the next decades

(Tybirk et al., 2017). As a downstream product of biogas production plants, LBM production requires two energy intensive processes: upgrading and liquefaction. Biogas produced through either an anaerobic digester or landfill must be upgraded in order to increase the methane (CH<sub>4</sub>) concentration (i.e. increase the heating value of the biogas) and remove harmful impurities in the final product. The upgraded biogas is known as biomethane, which contains mainly CH<sub>4</sub>. Typical biogas compositions and LBM purity requirements are presented in Table 1.

**Table.1 Composition of raw biogas.**

CONSTITUENTS	COMPOSITION
Methane	55-65
Carbon dioxide	35-45
Hydrogen Sulphide	0-1
Nitrogen	0-1
Hydrogen	0-1
Oxygen	0-2
Carbon monoxide	0-3

Based on the purpose of biogas utilization, one or a combination of conventional upgrading technologies such as water scrubbing, chemical absorption, pressure swing adsorption, or membrane separation can be applied (Angelidaki I et al., 2018).

In order to produce applicable biomethane in liquid form, the obtained biomethane from the upgrading processes must be liquefied in an external refrigeration cycle. Knowledge regarding refrigeration cycles is mature in terms of process design and energy optimization since it has been implemented in LNG plants for the past 100 years (He T et al., 2018; Lim et al., 2013; Chang et al., 2015). Cascade liquefaction processes, mixed refrigerant processes, and expander liquefaction processes (i.e. reverse Bryton cycles) are commercialized for liquefaction purposes (Austbo B et al., 2014). In advance of performing a comprehensive energy assessment of different LBM production plants in this paper, an overview regarding energy use of different biogas upgrading methods and liquefaction processes is provided in order to highlight advances and with respect to energy use.

## 1.2 BIOGAS UPGRADING

To date, a number of studies have focused on the energy aspects of different biogas upgrading methods. Rotunno et al., (2017) simulated a pressurized water scrubbing process considering a biogas mixture of 60 mol% CH<sub>4</sub> and 40 mol% CO<sub>2</sub>. They reported that a purity of 98.1 mol % CH<sub>4</sub> was obtained at 10 bar and 25 °C, which is suitable for gas grid injection and bio-CNG production. They stated that the energy efficiency of the upgrading plant producing biomethane with quality of gas grid injection was 89.8%. Budzianowski et al. (2017) considered various configurations of water scrubbing and water regeneration for a biogas mixture of 65 mol% CH<sub>4</sub> and 35 mol% CO<sub>2</sub>. Their results indicated that a specific energy use of 0.32 kWh/Nm<sup>3</sup> of raw biogas was required to produce biomethane with a purity of 98 mol% CH<sub>4</sub>, which was equivalent to 15.2% of the energy content of the raw biogas. Haider et al., (2016) simulated different types of membrane operating at different pressure for a mixture of CH<sub>4</sub> and CO<sub>2</sub> containing 60 mol% CH<sub>4</sub>. They stated that polyimide membranes in three stages upgraded the biogas up to 90 mol% CH<sub>4</sub> with specific energy of 0.22 kWh/Nm<sup>3</sup> of raw biogas. Iovane et al., (2014) conducted experimental studies considering polymeric membranes. They reported that the purity of biomethane reached 92 mol% CH<sub>4</sub> when the feed gas pressure was increased to 20 bar.

Valenti et al., (2016) investigated various designs for cellulose acetate membranes at 23 bars in order to upgrade a mixture of 60 mol% CH<sub>4</sub> and 40 mol% CO<sub>2</sub>. They reported that a specific energy use from 0.42 to 0.62 kWh/Sm<sup>3</sup>, depending on the design, was required to achieve purity of 97 mol% CH<sub>4</sub>. An overview of literature indicates that upgrading biogas to high quality biomethane, satisfying the purity requirements for LBM production, hardly can be achieved only through water scrubbing or membrane separation (Ullah Khan et al., 2017). Thereby, a polishing step should also be considered. Pressure swing adsorption (PSA) is a technology that can be used for both upgrading and polishing (Tybirk K et al., 2017). Ferella et al., (2017) performed experiments for low pressure PSA with different sorbents such as zeolite and activated carbon. They reported that biomethane with a purity of above 94 mol% CH<sub>4</sub> and a methane loss of 5% obtained using synthesized zeolite from fly ash. Augelite et al., (2017) simulated a novel two stage PSA configuration that upgraded a biogas mixture of 70 mol% CH<sub>4</sub> and 30 mol% CO<sub>2</sub>. They demonstrated that a biomethane stream with a purity of above 96 mol% CH<sub>4</sub>, and CO<sub>2</sub> with a purity of up to 97% were obtained from the novel configuration, while the required specific energy and methane loss were 0.42 kWh/kg of

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biomethane and about 3%, respectively. Recently, Liu et al., (2018) simulated a vacuum swing adsorption process for three-step adsorption beds and obtained CH<sub>4</sub> purity of 99.4 mol% from a feed gas of 50 mol% CH<sub>4</sub> and 50 mol% CO<sub>2</sub>. Their simulation showed a specific energy requirement of 0.22 kWh/kg of biomethane and biomethane recovery of 96.9%. Although the LBM requirements can be satisfied, high methane loss remains a challenge with PSA. Amine-based absorption is suitable not only for large industrial scale applications, but also for obtaining the targeted LBM specifications without requiring additional polishing steps (Tybirk K et al., 2017). The energy requirement for chemical absorption consists of work for biogas compression and heat at high temperature in range of 100–130 °C for amine regeneration in a stripper column (Sun Q et al., 2015). It is worth mentioning that the type of amine has great impact on the energy use in chemical absorption. For instance, biogas upgrading using mono-ethanolamine (MEA) requires more heat to regenerate the amine in stripper column than Methyl diethanolamine (MDEA) (Lange S et al., 2015). However, while the operating pressure is in the range 3–8 bar when using MEA, a pressure range of 45–70 bar is required for MDEA, depending on the purification requirements (Lange S et al., 2015; Najet T et al., 2018).

### **1.3 BIOGAS LIQUEFACTION**

In conventional approaches, the high quality biomethane obtained from the upgrading is cooled down through a separate liquefaction unit in order to produce LBM. Birgen and Jarque (2015) performed simulation using Aspen PLUS for liquefying biomethane generated from an up-grading process with a production capacity of 100 MWLHV of LBM. They showed that the total power requirement for a single expander liquefaction process was about 12.4 MW. Baccioli et al., (2018) simulated a dual-expander liquefaction process for small-scale LBM production. Results from their simulation indicated that 0.75 kWh/kg LBM was required for liquefaction process. In comparison with biogas upgrading, biomethane liquefaction has received limited attention in the literature.

### **1.4 ASPEN HYSYS**

Aspen HYSYS is a market-leading process modeling tool for conceptual design, optimization, business planning, asset management, and performance monitoring for oil & gas production, gas processing, petroleum refining, and air separation industries. Aspen HYSYS is a core element of Aspen Tech's aspen ONE Engineering applications. It has vast importance for chemical engineers to simulate a process. Aspen HYSYS has established itself as a very intuitive and easy to use process simulator in oil and gas refining industry. Users with little prior knowledge of Aspen HYSYS can pick up and train themselves in its modeling capabilities. Some of the very intuitive capabilities include a highly interactive process flow diagram for building and navigating through large simulations. It has efficient workflow for process design, equipment sizing, and preliminary cost estimation. The program also provides a very flexible and easy to use distillation column modeling environment. Additionally, the interactive nature of HYSYS enables users to build and use their models quickly and effectively.

Aspen HYSYS offers a comprehensive thermodynamics foundation for accurate calculation of physical properties, transport properties, and phase behavior for the oil & gas and refining industries. Comprehensive library of unit operation models including distillation, reactors, heat transfer operation, rotating equipment's, controllers and logical operations in both the steady state and dynamic environments. Process simulation is used for the design, development, analysis, and optimization of technical processes and is mainly applied to chemical plants and chemical processes, but also to power stations, and similar technical facilities. Process simulation is a model-based representation of chemical, physical, biological, and other technical processes and unit operations in software Basic prerequisites are a thorough knowledge of chemical and physical properties. Simulation is the imitation of the operation of a real-world process or system over time. Simulation can be used to show the eventual real effects of alternative conditions and courses of action. Simulation is also used when the real system cannot be engaged, because it may not be accessible, or it may be dangerous or unacceptable to engage, or it is being designed but not yet built, or it may simply not exist.

### **1.5 SIGNIFICANCE OF THIS STUDY**

Recovering a Liquefied Bio-Methane by High Pressure and Low-Pressure column using pressure swing method and make sure high quantity of yield. Models have been developed in Aspen HYSYS V12.0 considering a common raw biogas composition. Additionally, the design variables are optimized with respect to energy use. The following are some of the major significances of this study,

#### **1.5.1 Renewable Energy Source**

Biogas is a renewable energy source derived from organic waste, making it an environmentally friendly alternative to fossil

fuels. By converting it into liquefied biomethane, you're making it easier to transport and store, thus enhancing its usability and accessibility.

### 1.5.2 Reduced Greenhouse Gas Emissions

Biogas is primarily composed of methane, a potent greenhouse gas. By capturing and utilizing biogas, you're preventing its release into the atmosphere, thereby reducing greenhouse gas emissions and mitigating climate change.

### 1.5.3 Energy Security and Independence

Utilizing biogas for energy production promotes energy security and independence by reducing reliance on fossil fuels. Since biogas is produced from organic waste materials, its availability isn't subject to geopolitical tensions or fluctuations in fossil fuel markets.

### 1.5.4 Waste Management Solution

Converting organic waste into biogas not only generates renewable energy but also helps in waste management by diverting organic waste from landfills. This reduces the environmental impact associated with waste disposal and helps in minimizing odors and pollutants released from landfills.

### 1.5.5 Economic Benefits

The production of liquefied biomethane from biogas can create economic opportunities in terms of job creation, investment in infrastructure, and revenue generation from the sale of biomethane. Additionally, as the demand for renewable energy sources continues to grow, there is potential for further economic benefits from exporting liquefied biomethane.

## 2.PROCESS DESCRIPTION

Cryogenic separation integrated with liquefaction in a synergetic approach. In this case, cryogenic separation is integrated with the liquefaction process. Firstly, the raw biogas is used as a feed with appropriate conditions and delivered into the heat exchanger which is then separated using high pressure and low-pressure columns by following the principle of distillation. Here, we use pressure swing method to separate the mixtures as BM and LCO<sub>2</sub>.

Pressure-swing azeotropic distillation uses two columns operating at two different pressures to separate azeotropic mixtures by taking high-purity product streams from one end of the columns and recycling the streams from the other end with compositions near the two azeotropes. Then it is separated using a component separator, which separates the BM as vapour and LCO<sub>2</sub> as in liquid phase. This process helps to separate LCO<sub>2</sub> and BM with high purity content. The nitrogen is used as a coolant to liquify the Biomethane. This is then recycled to follow the same function after its use which helps to reduce the energy load in the coolers.

### 2.1 FEED COMPOSITION

The feed that is raw biogas stream consists of 60 mol % CH<sub>4</sub>, 39.9 mol% CO<sub>2</sub> and 0.1 mol% H<sub>2</sub>S at 35 °C and 1 atm. Liquefied biomethane (LBM) and liquefied CO<sub>2</sub> (LCO<sub>2</sub>) are considered as final product and byproduct of the LBM production plant, respectively. The conditions like temperature and pressure of biogas are tabulated in table 2,

**Table 2. Parameter of Raw Biogas**

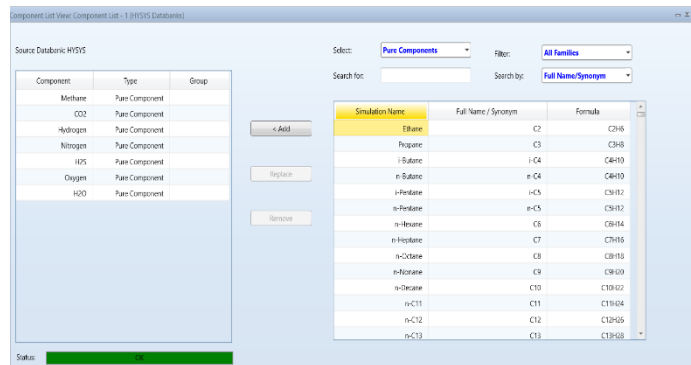
TEMP	35 °C
PRESSURE	100 kPa
MASS FLOW	1000 kg/h

The CO<sub>2</sub> content should be below 50 ppm for the LBM stream and above 99.7 mol% for the LCO<sub>2</sub> stream. Moreover, all the H<sub>2</sub>S from the raw biogas leaves the LBM production plant with the LCO<sub>2</sub> stream. In general, raw biogas generated from a biogas production plant contains water. Depending on the type of biogas upgrading method, dehydration can be accomplished before or after the upgrading step. For instance, removal of water in a cryogenic gas separation is carried out before the upgrading step. For upgrading based on chemical absorption, the dehydration unit is placed after the upgrading step, as the amount of water removal depends on the water content at the outlet of the absorber. In this study, it is assumed that the raw biogas does not contain water, or alternatively is removed prior to upgrading. Therefore, no dehydration unit was considered for this case.

### 2.2 PROCESS MODELLING

The complete processes are simulated with the commercial process simulator Aspen HYSYS V12.0. In order to characterize the phase behavior of the mixtures that are involved in this study, two different thermodynamic models were selected from

the Aspen HYSYS property selections. In accordance with the thermodynamic modeling validation by Lange et al., (2018) the Soave-Redlich-Kwang (SRK) equation of state is used for the cryogenic upgrading scheme and refrigeration cycles, whereas the “acid gas - chemical solvent” package, as recommended by Aspen Technology (Kelley et al., 2011), is employed for the chemical absorption upgrading scheme. The components are selected and shown in fig. 1.



**Fig. 1 List of Components Selected**

In addition, the following assumptions are considered for both configurations:

The pressure drop in coolers, heat exchangers, distillation columns and dehydration units are negligible.

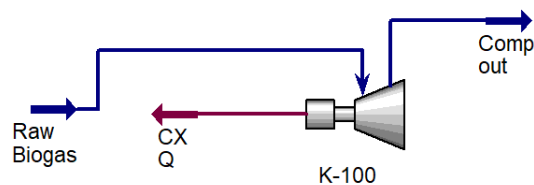
1. An identical isentropic efficiency of 80% is considered for compressors, expanders and pumps.
2. Minimum temperature approach in the multi stream heat exchangers of the refrigeration cycles is 2 °C.
3. Inlet and outlet temperature of cooling-water in heat exchangers are 20 and 25 °C, respectively.
4. Gas compression units contain four stages of compressors with identical pressure ratio and intercooling to 35 °C.
5. Moreover, the CO<sub>2</sub> freeze-out utilization tool in Aspen HYSYS is employed to ensure that CO<sub>2</sub> ice is not forming during LBM production (Stoecker, 1989).

### 2.2.1 Process Optimization

In order to ensure that the two studied configurations are run at a minimum energy requirement to produce the LBM, the processes are optimized using an exhaustive search method. In this method, a number of combinations of the values of independent variables is examined through Aspen HYSYS and results are then analyzed using spreadsheets with respect to optimization constraints. The optimization procedure is performed for the two proposed configurations, in which the raw biogas consisted of 60 mol% CH<sub>4</sub>, 39.9 mol% CO<sub>2</sub> and 0.1 mol% H<sub>2</sub>S. A two-step successive optimization procedure is considered for case 1. In the first step, the total cooling duty of the upgrading step is minimized, which includes the cooling requirement in the condensers of the columns, precooling of the raw biogas in HX1 and sub-cooling the biomethane in HX2. The second step minimizes electrical work that is needed for the liquefaction process.

### 2.3 DESIGN AND PARAMETERS

The parameters for expander, heat exchangers, distillation columns and compressors are selected based on comprehensive analysis. Firstly, the raw biogas is connected to an expander which helps to increase the pressure and temperature of the feed. The pressure of the expander is set to 5050 kPa. The outlet from the expander is connected to an external heat exchanger which is followed by the distillation columns. The expander is shown in the fig. 2.



**Fig. 2 Design of the Expander**

Worksheet	Raw Biogas	Comp out	CX Q
Name	15000	15000	-empty-
Conditions			
Temperature (C)	35.00	307.3	-empty-
Pressure (kPa)	100.0	5050	-empty-
Molar Flow (kgmole/h)	1000	1000	-empty-
Mass Flow (kg/h)	2.722e+004	2.722e+004	-empty-
Std. Heat cap. (kJ/Flow (mole))	33.47	33.47	-empty-
Molar Enthalpy (kJ/kgmole)	-2.017e+005	-1.902e+005	-empty-
Molar Entropy (kJ/kgmole-C)	106.7	179.9	-empty-
Heat Flow (kJ/h)	-2.017e+008	-1.902e+008	-1.546e+007

**Fig. 3 Design parameters of the Expander**

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### 2.3.1 Design of Heat Exchanger

The Heat Exchanger (LNG) is placed and the outlet and inlet streams are connected. The expander's outlet is connected with the inlet stream of the heat exchanger. Meanwhile, the outlet stream of the heat exchanger, which is named as high pressure inlet, is connected with the high pressure distillation column. The reason for using a plate type heat exchanger is that we can use multiple inlets and outlets. The parameters and the design are shown in the fig. 4 and 5 respectively.

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Property	Comp out	High Pressure Inlet
Vapour	1.0000	1.0000
Temperature (C)	207.9	-18.88
Pressure (kPa)	5050	3950
Molar Flow (kgmole/h)	1000	1000
Mass Flow (kg/h)	2.722e+054	2.722e+054
Std Ideal Liq Vol Flow (m3/h)	53.47	53.47
Molar Enthalpy (kJ/kgmole)	-1.802e+005	-2.051e+005
Molar Entropy (kJ/kgmole-C)	178.9	142.9
Heat Flow (kJ/h)	-1.902e+008	-2.051e+008

Fig. 4 Design parameters of the Heat Exchangers

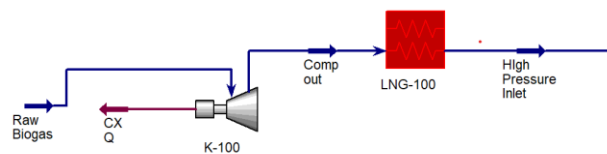


Fig. 5 Design of the Heat exchanger

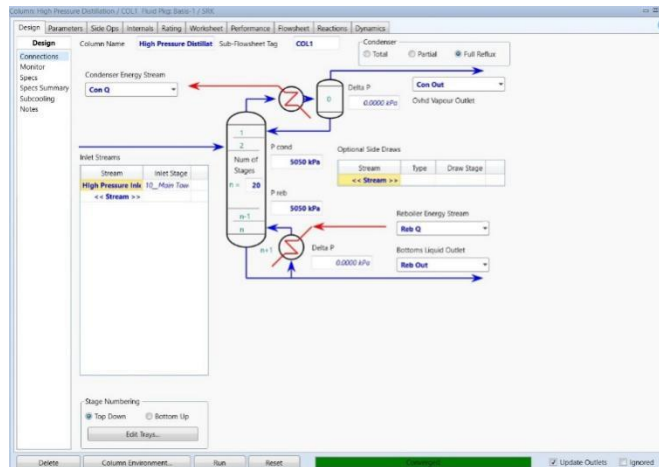
### 2.3.3 Design of Distillation Columns

The next step is to separate the outlet from heat exchanger which contains methane, CO<sub>2</sub> and H<sub>2</sub>S. This can be done by using distillation columns. Distillation is a process of separating a mixture based on their relative volatility. Two distillation columns namely High pressure and low-pressure distillation columns are used. The number of stages for high pressure and low pressure columns are 20 and 22 respectively according Hashemi et al., 2019. The feed is introduced in 10 and 13<sup>th</sup> stages respectively. The data used for both the distillation columns are tabulated in Table. 2

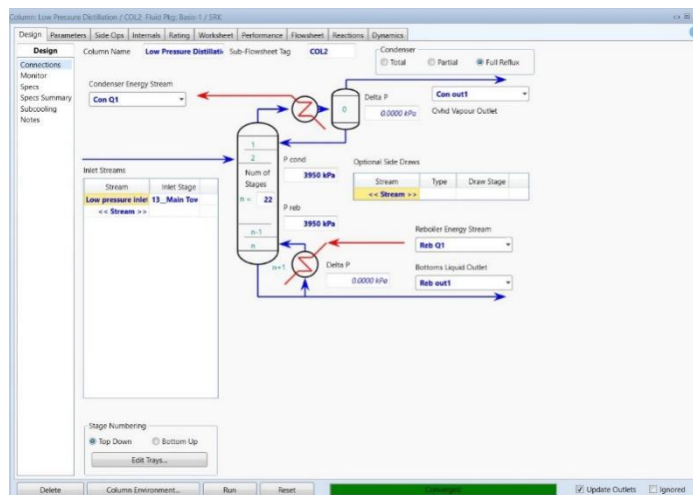
Table 3. Parameters for High and Low Pressure Distillation Columns

Conditions	High Pressure Column	Low Pressure Column
Number of Stages	20	22
Column Diameter	1.5	1.5
Feed Stage No. (From top)	10	13
Pressure (kPa)	5050	3950
Condenser Temperature °C	-70.3	-87.3
Reboiler Temperature °C	13.8	4.1
Reflux Ratio	2.5	2.5

The Parameters of the distillation columns are shown in fig. 6 and 7 for both high pressure and low pressure columns respectively.



**Fig. 6 High Pressure Distillation Column**



**Fig. 7 Low Pressure Distillation Column**

### 2.3.4 DESIGN OF THE COOLANT

The coolant used here is nitrogen which is considered in this case as a refrigerant. This refrigeration cycle helps to decrease the energy load in the coolers. Nitrogen is fed as inlet of an expander which increases the pressure of the flow and it is cooled at set value which then passes through as inlet in the heat exchanger. Followed by cooling in the heat exchanger and is passed through an expander to decrease the pressure. This nitrogen is then passed as an inlet in a secondary heat exchanger which cools the liquified biomethane. Further the nitrogen is recycled and starts to do the same throughout the process. The parameters and compositions are shown in the fig. 8.



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Worksheet	Stream Name	N2	Vapour Phase
Conditions	Vapour / Phase Fraction	1.0000	1.0000
Properties	Temperature [C]	32.00	32.00
Composition	Pressure [kPa]	250.0	250.0
Oil & Gas Feed	Molar Flow [kgmole/h]	6500	6500
Petroleum Assay	Mass Flow [kg/h]	1.821e+005	1.821e+005
K Value	Std Ideal Liq Vol Flow [m3/h]	225.8	225.8
Notes	Molar Enthalpy [kJ/kgmole]	189.4	189.4
User Variables	Molar Entropy [kJ/kgmole-C]	141.2	141.2
Cost Parameters	Heat Flow [kJ/h]	1.231e+006	1.231e+006
Normalized Yields	Liq Vol Flow @Std Cond [m3/h]	1.537e+005	1.537e+005
Emissions	Fluid Package	Basis-1	
	Utility Type		

**Fig. 8 Parameters for the Coolant.**

The refrigerant that is nitrogen after passing through the expander flows into the cooler in which the inlet is named as cooler in set at a pressure of 3500 kPa. The outlet is named as cooler out with a temperature and pressure of 35 °C and 7000 kPa respectively. The parameters for it are shown in the fig. 9 and 10.

Worksheet	Stream Name	Cooler in	Vapour Phase
Conditions	Vapour / Phase Fraction	1.0000	1.0000
Properties	Temperature [C]	468.5	468.5
Composition	Pressure [kPa]	3500	3500
Oil & Gas Feed	Molar Flow [kgmole/h]	6500	6500
Petroleum Assay	Mass Flow [kg/h]	1.821e+005	1.821e+005
K Value	Std Ideal Liq Vol Flow [m3/h]	225.8	225.8
Notes	Molar Enthalpy [kJ/kgmole]	1.350e+004	1.350e+004
User Variables	Molar Entropy [kJ/kgmole-C]	146.0	146.0
Cost Parameters	Heat Flow [kJ/h]	8.772e+007	8.772e+007
Normalized Yields	Liq Vol Flow @Std Cond [m3/h]	1.537e+005	1.537e+005
Emissions	Fluid Package	Basis-1	
	Utility Type		

**Fig. 9 Parameters of Cooler In.**

Worksheet	Attachments	Dynamics	
<b>Worksheet</b>	Stream Name	Cooler out	Vapour Phase
Conditions	Vapour / Phase Fraction	1.0000	1.0000
Properties	Temperature [C]	35.00	35.00
Composition	Pressure [kPa]	7000	7000
Oil & Gas Feed	Molar Flow [kgmole/h]	6500	6500
Petroleum Assay	Mass Flow [kg/h]	1.821e+005	1.821e+005
K Value	Std Ideal Liq Vol Flow [m3/h]	225.8	225.8
User Variables	Molar Enthalpy [kJ/kgmole]	-66.77	-66.77
Notes	Molar Entropy [kJ/kgmole-C]	112.6	112.6
Cost Parameters	Heat Flow [kJ/h]	-4.340e+005	-4.340e+005
Normalized Yields	Liq Vol Flow @Std Cond [m3/h]	1.537e+005	1.537e+005
Emissions	Fluid Package	Basis-1	
	Utility Type		

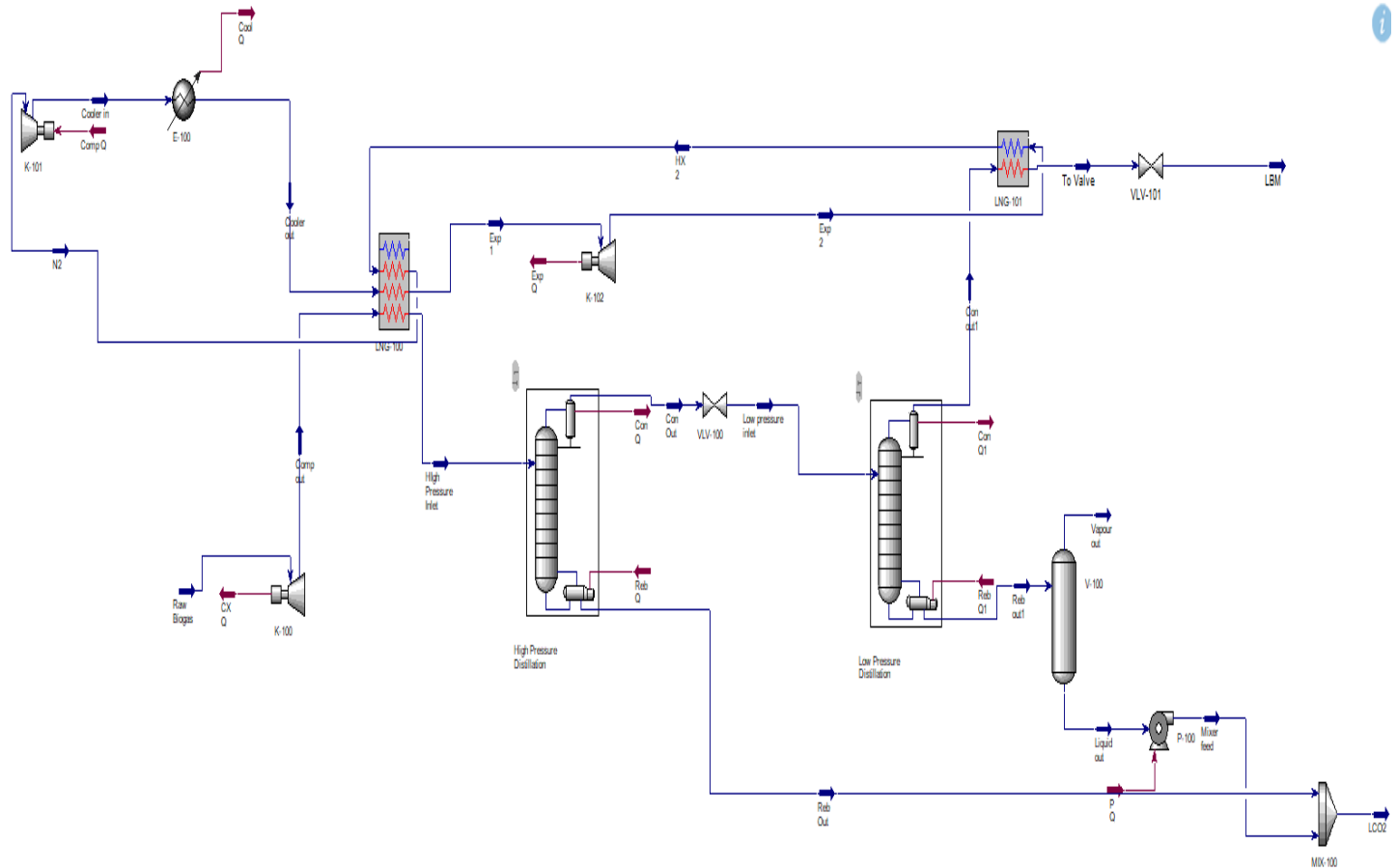
Fig. 10 Parameters of Cooler Out

The Nitrogen then goes into the inlet of the expander in order to decrease the pressure of the flow from 7000 kPa to 290 kPa. The parameters for this is shown in the fig. 11.

Worksheet	Attachments	Dynamics	
<b>Worksheet</b>	Stream Name	Exp 1	Vapour Phase
Conditions	Vapour / Phase Fraction	1.0000	1.0000
Properties	Temperature [C]	-36.00	-36.00
Composition	Pressure [kPa]	7000	7000
Oil & Gas Feed	Molar Flow [kgmole/h]	6500	6500
Petroleum Assay	Mass Flow [kg/h]	1.821e+005	1.821e+005
K Value	Std Ideal Liq Vol Flow [m3/h]	225.8	225.8
User Variables	Molar Enthalpy [kJ/kgmole]	-2453	-2453
Notes	Molar Entropy [kJ/kgmole-C]	103.8	103.8
Cost Parameters	Heat Flow [kJ/h]	-1.595e+007	-1.595e+007
Normalized Yields	Liq Vol Flow @Std Cond [m3/h]	1.537e+005	1.537e+005
Emissions	Fluid Package	Basis-1	
	Utility Type		

Fig. 11 Parameters of the Expander inlet

The expander inlet parameters calculate the other parameters automatically. This then follows into the heat exchanger which further cools down the liquified biomethane to reach a temperature of below negative degree Celsius which will make the Biomethane into liquid form. The overall Design is shown in the fig. 12.



### 3. RESULTS AND DISCUSSION

The objective of this case study was to optimize the process parameters for efficient LBM production. The Aspen HYSYS simulation yielded a high purity of 99.85% liquefied biomethane as the primary product. This indicates efficient conversion of biogas into a valuable fuel source suitable for various applications. Additionally, the simulation produced 99.53% liquefied carbon dioxide as a by-product. While not the primary target, the high purity of LCO<sub>2</sub> suggests an effective utilization of the carbon dioxide component of the biogas feedstock. The Distillation column plays a major role in controlling the separation of methane and CO<sub>2</sub>. A valve with appropriate pressure is set between the two columns to control the flow. Nitrogen which acts as an external coolant is used as a source of refrigerant to reduce the load in the coolers. This in turn helps to reduce the energy consumption. The component separator is used to separate Liquefied CO<sub>2</sub> and other impurities as vapour product. The achieved purity levels demonstrate the effectiveness of the process in separating methane and carbon dioxide from the biogas feed. The high conversion efficiency reflects the robustness of the process design and its potential for practical application. Further economic analysis is warranted to evaluate the feasibility of scaling up the process for industrial production. Factors such as energy consumption, equipment costs, and market value of liquefied biomethane and carbon dioxide will influence the economic viability of the process.

#### 3.1 OVERALL MATERIAL BALANCE

The overall material balance for all the components used are shown through figures. This helps to calculate the overall input and output in an orderly manner. The Material Balance are shown in fig. 13.

Name	Chiller Out	Exp in	HX2 in	HX1 in	Low Dist Out
Vapour Fraction	1.0000	1.0000	1.0000	1.0000	1.0000
Temperature (C)	35.00 *	-36.00 *	-155.9	-130.0	-70.75
Pressure (kPa)	7000 *	7000	258.0 *	258.0	5000
Molar Flow (kgmole/h)	6400	6400	6400	6400	658.2
Mass Flow (kg/h)	1.793e+005	1.793e+005	1.793e+005	1.793e+005	1.221e+004
Liquid Volume Flow (m3/h)	222.3	222.3	222.3	222.3	35.25
Heat Flow (kJ/h)	-4.273e+005	-1.570e+007	-3.375e+007	-2.892e+007	-7.226e+007

Name	Reb Out 1	Low Pressure Input	Reb Out 2	Cond Out 2	To Mixer
Vapour Fraction	0.0000	0.8876	0.0001	1.0000	0.0000
Temperature (C)	14.00	-78.64	4.691	-87.70	6.194
Pressure (kPa)	5050	3950	3950	3950	5050 *
Molar Flow (kgmole/h)	341.8	658.2	58.23	600.0	58.22
Mass Flow (kg/h)	1.501e+004	1.221e+004	2562	9651	2562
Liquid Volume Flow (m3/h)	18.22	35.25	3.104	32.15	3.104
Heat Flow (kJ/h)	-1.379e+008	-7.226e+007	-2.365e+007	-4.899e+007	-2.364e+007

Name	Vap Out	To pump	LCO2	To Exp 2	LBM
Vapour Fraction	1.0000	0.0000	0.0000	0.0000	0.0525
Temperature (C)	4.691	4.691	13.03	-155.4	-161.5
Pressure (kPa)	3950	3950	5050	3950	100.0
Molar Flow (kgmole/h)	8.135e-003	58.22	400.0	600.0	600.0
Mass Flow (kg/h)	0.3579	2562	1.757e+004	9651	9651
Liquid Volume Flow (m3/h)	4.337e-004	3.104	21.32	32.15	32.15
Heat Flow (kJ/h)	-3226	-2.365e+007	-1.615e+008	-5.383e+007	-5.383e+007

Fig. 13 Material balance of the Overall Process.

### 3.2 OVERALL ENERGY BALANCE

The Energy Balance is done by Aspen HYSYS by Calculating the energy load used for each components. The Energy balance is shown in the fig. The production of liquefied biomethane offers environmental benefits by providing a renewable and low-carbon alternative to traditional fossil fuels. Additionally, the capture and utilization of carbon dioxide as a by-product contribute to reducing greenhouse gas emissions, aligning with sustainability objectives.

Future research could focus on optimizing process parameters to further enhance product purity, increase conversion efficiency, and reduce energy consumption.

Energy Streams						Fluid Pkg:	All
Name	C1	Comp Q	Chill Q	Exp q1	Cond Q1		
Heat Flow (kJ/h)	-1.149e+007	8.516e+007	8.680e+007	1.805e+007	7.345e+006		
Name	Reb Q	Cond Q2	Reb Q2	P1			
Heat Flow (kJ/h)	2.310e+006	6.719e+006	6.329e+006	4165			

Fig. 14 Energy Balance of the Overall Process

### 4. CONCLUSION

Complete models to produce LBM from raw biogas have been considered and optimized using Aspen HYSYS V12.0. In this case, a cryogenic biogas upgrading method by means of two distillation columns at different pressure is integrated with liquefaction followed by a refrigeration cycle. The raw biogas comprises a mixture of 60 mol% CH<sub>4</sub>, 39.9 mol% CO<sub>2</sub> and 0.1 mol% H<sub>2</sub>S. Important design variables of models were optimized using an exhaustive search method in order to minimize the energy use of the model. Furthermore, results from energy distribution reveal that the main share of required work in the LBM production is used in liquefaction, approximately 81% in this case respectively. Therefore, considering an appropriate type of liquefaction process with respect to the biogas upgrading method is worth being studied further. Meanwhile, heat integration potential from the LBM production plants can also be investigated in further work. For this future work, a more comprehensive optimization method should be applied.

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