Journal of Advanced Research in Fluid Mechanics and Thermal Sciences 112, Issue 1 (2023) 106-124

Journal of Advanced Research in Fluid Mechanics and Thermal Sciences

Journal homepage:
https://semarakilmu.com.my/journals/index.php/fluid_mechanics_thermal_sciences/index
ISSN: 2289-7879

Plant Design and Techno-Economy Analysis of Floating Liquefied Natural Gas (FLNG) in Masela Block

Muhammad Fakhrizal Fahmi[1], Renanto Handogo[1,*], Juwari Purwo Sutikno[1], Rendra Panca Anugraha[1], Alhafiz Taufiqul Hakim[1], Aisyah Putri Prameswari Jasmine[1]

[1] Department of Chemical Engineering, Faculty of Industrial Technology and Systems Engineering, Institut Teknologi Sepuluh Nopember, Sukolilo, Surabaya 60111 Indonesia

ARTICLE INFO

Article history:
Received 28 August 2023
Received in revised form 13 November 2023
Accepted 25 November 2023
Available online 15 December 2023

Keywords:
Liquefied natural gas; offshore; floating; Masela block; techno-economy

ABSTRACT

The prospects of the natural gas industry in Indonesia are very great. Considering that Indonesia has large enough natural gas reserves of 62.4 trillion cubic feet, of which 43.6 trillion cubic feet are proven. In fact, about one-third of the world's natural gas reserves are offshore. For the utilization of offshore gas production itself, it usually uses pipelines for gas distribution from offshore production facilities to the mainland commonly referred to as onshore terminals. The establishment of an offshore liquefied natural gas (LNG) plant is the solution to maximize the utilization of natural gas resources. The aim of this research is a preliminary study that obtains a decision on an effective method and economic parameters of the development plan required for an efficient process to provide maximum floating LNG plant investment and profitability. The pre-designed offshore LNG plant is planned to be commissioned in 2025 with a production capacity of 2.5 MTPA. The location for the construction of this plant is planned in the Masela Block area. It will operate continuously 24 hours a day for 330 days with raw materials of 315128 kg of natural gas/hour, producing LNG products of 230768 kg/hour, Liquefied Petroleum Gas (LPG) of 5800 kg/hour, and condensate products of 356 kg/hour. The production process of this offshore LNG plant can be divided into 4 processes, namely acid gas removal, dehydration unit, fractionation, and liquefaction, which are considered to be common processes based on low cost and high efficiency. From an economic point of view, the Internal Rate of Return (IRR) obtained at 12.3% is above the bank loan interest rate, which is 8% with a payback period (POT) of 4.81 years, which is smaller than the repayment time set by the lender, which is 10 years, and break-even point (BEP) has reached 36% that just acceptable which refers to the economic sustainability of plant development. Therefore, offshore LNG plants are feasible to be established.

1. Introduction

Natural gas is a fossil fuel formed from the remains of marine organisms trapped in the subsoil for millions of years. Natural gas is composed of a mixture of hydrocarbon gases where the gases are flammable compounds. Natural gas can produce clean combustion reactions and produces almost

* *Corresponding author.*
E-mail address: renanto@chem-eng.its.ac.id

https://doi.org/10.37934/arfmts.112.1.106124

no exhaust emissions that can damage the environment. In addition to containing methane, natural gas can also contain ethane, propane, butane, pentane, and other heavier fractions and impurities. In natural gas processing, in general, there are two technological concepts that can be used, namely the concepts of CNG (Compressed Natural Gas) and LNG. In the CNG concept after being processed to remove impurities and heavy hydrocarbons, the gas is compressed to ±250 bar. In the LNG (Liquefied Petroleum Gas) concept, after it has been processed, the gas is cooled to -160°C in the atmosphere to change the gas phase to liquid (liquefaction). With the liquefaction of the gas, the specific volume of natural gas can shrink up to 1/600 times compared to its initial condition at standard temperature and pressure. The classification of Natural Gas Processing based on the range of gas distribution and production is illustrated in Figure 1 where LNG technology is very suitable for use in natural gas processing because it facilitates transportation and has storage with a larger capacity [1]. In LNG technology, natural gas can be stored in atmospheric tanks and then transported in large quantities to distant places using special LNG tankers where gas transportation using pipelines is not possible or economical.

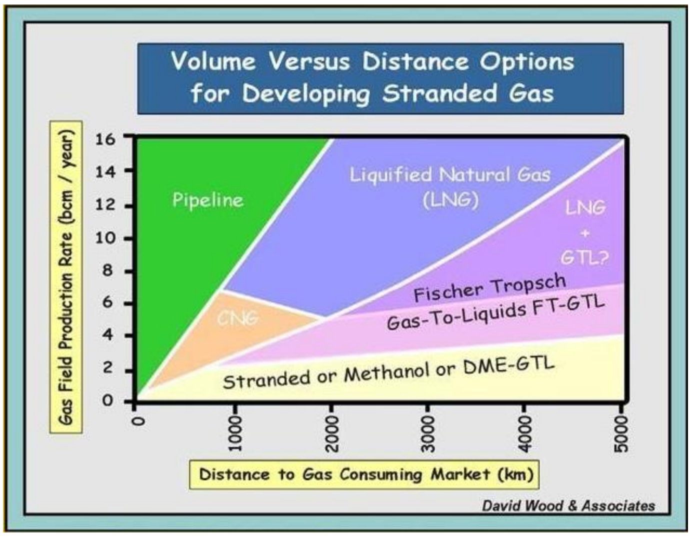

Fig. 1. Natural Gas Processing Technology Selection Chart

As can be seen in Figure 2, for short distances, gas transportation using pipelines in places where it is possible to install piping systems is considered more economical compared to LNG systems. However, the LNG system is more competitive for long-distance transportation routes, especially those across the ocean because the total cost obtained is relatively low and not much affected by the distance of transportation to consumers. Therefore, this LNG technology is very suitable for use in Indonesia, which is an archipelagic country and a maritime country [2].

The global demand for LNG increased significantly during the previous few decades, rising from 50 million tons in 1990 to over 240 million tons in 2011. The world's massive conventional gas resources were mostly used to finance this amazing growth [3]. Indonesia has very large natural gas reserves and is spread in various regions. Figure 3 illustrates the availability of gas reserves in several oil and gas-producing provinces in Indonesia where the potential for the natural gas industry in Indonesia is considerable, given Indonesia's reserves of 60.6 trillion cubic feet, with 41.6 trillion cubic feet considered proven and 10.2 trillion cubic feet potentially discovered [4].

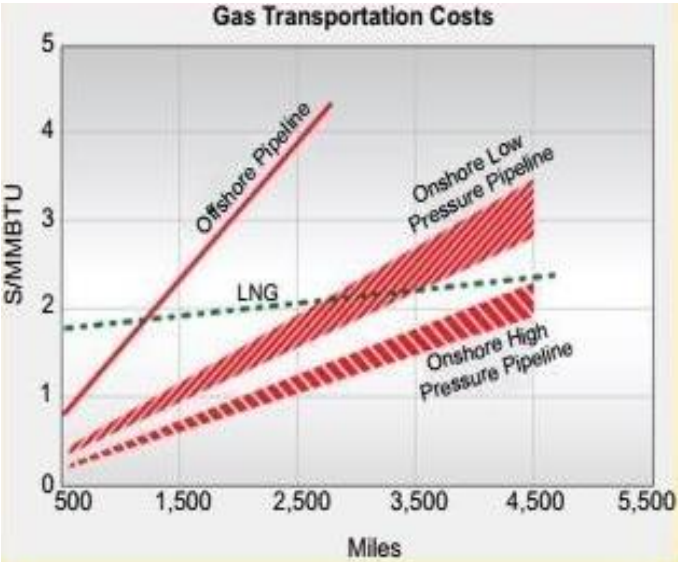

Fig. 2. Comparison of Gas Transportation Costs Through Pipeline (for 1 TCF/year and includes regasification costs)

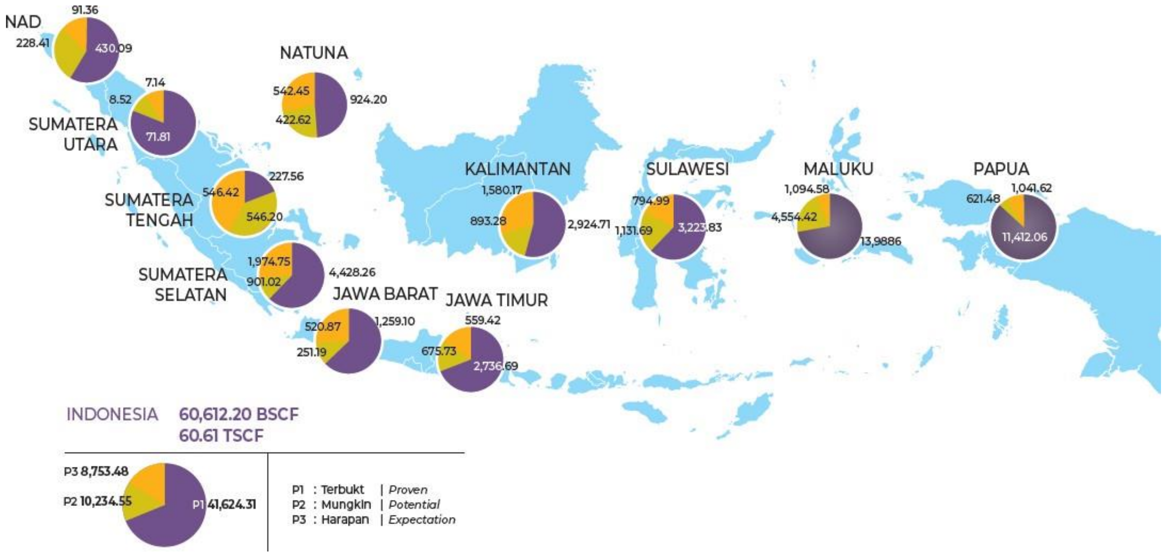

Fig. 3. Indonesia's Natural Gas Reserves in 2020

The creation of innovative floating unit designs that can handle massive amounts of hydrocarbon is being encouraged by the rising demand for natural gas. Offshore facilities that generate, process, and store liquefied natural gas (LNG) are known as FLNG (Floating Liquefied Natural Gas) units. Once an FLNG's topside and tanks are larger and more intricate than those of a standard FPSO vessel, a design process taking these specifics into account is required [5]. Onshore refineries are easier to reach than offshore refineries because the location of the refinery itself can be in the middle of a forest, mountain peak, middle of desert, or even on the edge of a city or village. The provisions needed to make a borewell on land are somewhat easier than offshore. However, because there has been a lot of exploration and exploitation on land, the chances of finding new oil and gas reserves are smaller than in the ocean. The Ministry of Energy and Mineral Resources in Indonesia has initiated a plan to expand refinery capacity in remote areas to maximize energy reserves in Indonesia. Researchers have conducted studies related to process design and economic analysis for refinery development in remote areas such as those conducted by Anugraha *et al.,* [6] and Handogo *et al.,* [7]. They have analyzed the process of small-scale oil refineries including optimization and economic analysis. Their findings will further serve as a reference for the feasibility assessment of developing other energy facilities such as gas plant refineries in remote areas, especially in offshore.

In fact, about one-third of the world's natural gas reserves are offshore. For the utilization of offshore gas production itself, it usually uses pipelines for gas distribution from offshore production facilities to the mainland commonly referred to as onshore terminals. However, gas distribution through new pipelines can be economically carried out if the gas production is adequate at a relatively close distance. This is the reason why offshore gas is difficult to bring ashore to be utilized. Thus, the solution to maximizing the utilization of natural gas resources is to establish an offshore LNG Plant.

In general, the difference in facilities for onshore and offshore fields lies in the location of the plant as shown in Figure 4. Offshore LNG plants use a ship designed as a floating facility and the design procedure itself is not much different from the onshore terminal. Problems with limited area, environment, safety, and security also encourage the existence of LNG-receiving terminals offshore. The offshore LNG Plant needs some support ship called an LNG carrier is made specifically for carrying liquefied natural gas to the nearest receiving terminal [8].

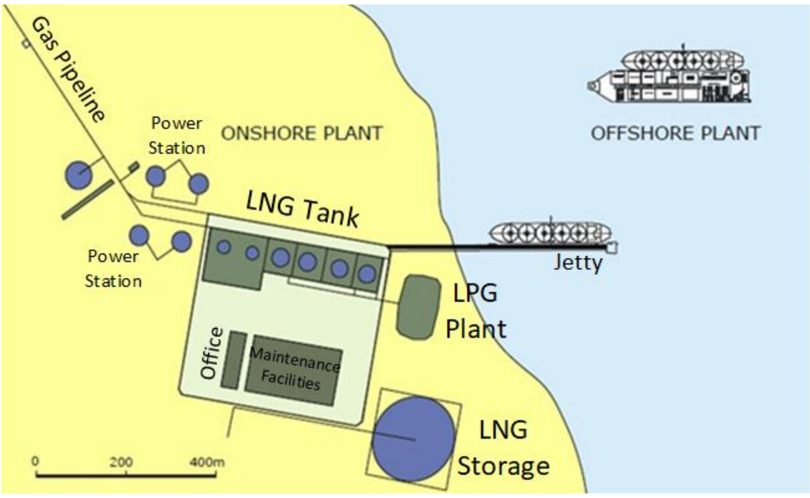

Fig. 4. Differences between onshore and offshore LNG plants

The design, permitting, and construction processes are all shorter, so it will take faster for an offshore LNG plant to start operations compared to an onshore LNG plant. In addition, offshore LNG is considered more economical than onshore LNG and the economics of LNG production must be contrasted with the price of piping gas. Since floating LNG facilities can be easily transferred to new fields as the present ones fail, LNG is more affordable for the development of numerous remote gas fields. To satisfy certain patterns of gas consumption, LNG may also be stored [9].

LNG demand in Indonesia itself is quite large because the available LNG supply is prioritized to meet domestic LNG needs in accordance with the regulation of the Minister of Energy and Mineral Resources number 06 of 2016 so that the supply of natural gas for export decreases. Table 1 shows the domestic natural gas utilization in 2016-2021.

Table 1
Domestic Natural Gas Fulfillment Utilization Per Sector 2016 to 2021

Data Type	Unit	2016	2017	2018	2019	2020	2021
Total natural gas utilization	BBTUD	6.856,66	6.616,77	6.664,53	6.140,10	5.701,06	5.734,41
Domestic realization	BBTUD	3.996,84	3.880,40	3.995,05	3.984,76	3.592,82	3.687,59
Export Realization	BBTUD	2.859,82	2.736,37	2.669,48	2.155,34	2.108,24	2.046,82

LNG demand for the world is expected to grow 3.4 percent annually through 2035, with about 100 million metric tons of additional capacity needed to meet growth and demand from existing projects. LNG demand growth will slow considerably but will still grow by 0.5 percent from 2035 to 2050 with more than 200 million metric tons of new capacity needed by 2050 [10]. Most gas reserves worldwide are located offshore, including Indonesia. As an alternative to onshore LNG plants, FLNG (floating LNG) plants are being developed. FLNG plants have several important advantages over traditional onshore LNG plants, such as eliminating the need for platforms, pipelines, and ports, thereby significantly reducing capital costs due to infrastructure requirements; can also reduce environmental impacts, especially if a potential onshore plant is located near a populated area; and can be moved to a new location when the original gas field becomes depleted [11]. This is also supported by a study conducted by Giranza and Bergmann [12], which evaluated and compared the economic viability of an onshore LNG plant and a floating LNG plant in Indonesia. The study concluded that a FLNG facility has a better return on investment than a conventional onshore LNG facility. This is due to the ability of offshore technology to have mobile storage and regasification facilities, which results in lower investment costs and higher termination and shutdown costs for onshore projects. On the other hand, Khoiriyah *et al.,* [13] have made a small-scale design concept base of a floating storage and regasification unit (FSRU) with a capacity of 60-70 MW which is used to estimate the LNG requirements to be used so that the preliminary design study of the floating LNG plant is a form of follow-up to the FSRU design.

Process selection especially in LNG plants can be used to compare cost and efficiency for plant investment and operation. He *et al.,* [14] provide a comparison study to choosing refrigerant in an LNG Plant. Modified mixed refrigerant liquefaction process (MSMR) and parallel nitrogen expansion liquefaction process (PNEC) will be optimized to minimize specific energy consumption and total investment of the options. The comparison results showed that MSMR had a lower specific energy consumption, higher exergy efficiency, lower total investment, and higher flexibility than PNEC so mixed refrigerant can be a great choice to support the liquefaction process. For the acid gas removal unit (AGRU) selection process, Rufford *et al.,* [15] evaluated different technologies based on absorption, distillation, adsorption, membrane separation, and hydrates to compare were made with designs to produce pipeline gas (typically 2% CO_2, <3% N_2) and gas to supply cryogenic gas plants (typically 50 ppmv CO_2, 1% N_2). Amine-based absorption technologies for sour gas treatment are well-established in the natural gas industry. Its use for large-scale gas treatment applications is well established as the process has high separation capability for CO_2 (and H_2S) and the technology has been proven. On dehydration units, Ciahotný *et al.,* [16] have experimented with different adsorbents for different specifications of natural gas used for CNG stations. A series of tests were conducted in this study including testing adsorbent properties in dry air, adsorption capacity for water vapor based on relative humidity, and comparison of water vapor pressure to adsorption capacity. It was found that adsorbents with smaller pore sizes had higher total adsorption capacity for water vapor. Then, research on absorbents using glycol components for the dehumidification process of natural gas was also studied by Smulski and Sacha [17]. ethylene glycol (EG), diethylene glycol (DEG), triethylene glycol (TEG), and tetra ethylene glycol (TREG) will be carried out laboratory-scale tests using convection heat to measure mass concentration for each temperature change. As a result, TEG and TREG are better for obtaining high concentrations than EG and DEG for the application of high regeneration temperatures. All of the process selections previous study can be determined as the most effective method that may be used for alternative features in floating LNG Plants. Seeing that the natural gas reserves owned by Indonesia are very large, of course, the prospect of LNG marketing will be very good because of the huge demand. In order to present an opportunity for a floating LNG market, a preliminary study that obtains a decision on an effective method and economic parameters of the development plan is required for an efficient process to provide maximum floating LNG plant investment and profitability.

2. Methodology

2.1 Data Collection, Plant Location, and Plant Capacity

In this offshore LNG plant, the main raw material used is natural gas from gas wells in the Abadi gas field in the Maluku region. Indonesia itself has very large natural gas reserves and is spread in various regions. The potential for a significant LNG industry in Indonesia is obvious given the country's vast natural gas reserves, over sixty trillion cubic feet, approximately 70% proven [18]. In this offshore LNG plant, the main raw material used is natural gas. The composition of natural gas can vary according to the source of the gas field. Table 2 shows the composition of natural gas in general.

Table 2
Pure natural gas content composition in general

Component	The Composition of gas (%)	Chemical Structure	Heating Value (BTU/lb)
Methane	70 – 95	CH_4	23.571
Ethane	2,5 – 12	C_2H_6	21.876
Propane	1 – 6	C_3H_8	21.646
Butane*	0,2 – 2,5	C_4H_{10}	21.293
Pentane	0,2 – 1	C_5H_{12}	20.877

*Butane includes iso and N forms

The main contaminant or impurity of natural gas is usually a mixture of organosulfur and hydrogen sulfide (H_2S) that must be separated before it can be used or processed further. In addition, natural gas also contains components H_2O, CO_2, N_2, and O_2 in small quantities [19]. In this Masela Block FLNG plant, the main raw material used is natural gas from gas wells in the Abadi gas field. The following is data on the composition of natural gas in the Masela Block on a dry basis in Table 3 [4].

Table 3
Pure natural gas content composition in Masela Block

Component	% Mole	Component	% Mole	Component	% Mole
N_2	0.933	C_3H_8	1.512	n-C_5H_{12}	0.157
CO_2	9.291	i-C_4H_{10}	0.296	C_6H_{14}	0.23
CH_4	81.49	n-C_4H_{10}	0.143	C_7H_{16}+	1.474
C_2H_6	4.288	i-C_5H_{12}	0.187	H_2S	0.001

Currently, most natural gas is processed into Liquefied Natural Gas (LNG) and Liquefied Petroleum Gas (LPG). LNG and LPG are used as industrial and residential fuels, as well as raw materials for the petrochemical industry. The rest of the liquefaction of natural gas condensates. Condensate is like crude oil with the best quality.

The estimated amount of natural gas supply and national natural gas demand for a certain number of times is depicted in a balance sheet called the Indonesian Natural Gas Balance. If the need for natural gas in an area is greater than the existing supply, then it is said that the natural gas balance is not balanced and there is a shortage of supply (gas shortage), and vice versa If the supply exceeds the demand, then it is said that there is an oversupply (surplus gas).

Based on Indonesia's Natural Gas Balance for 2018-2027 in Figure 5, domestic demand until 2024 is met for all scenarios used. However, scenarios 2 and 3 indicate that the national gas balance will experience a gas surplus in the next few years but may face a deficit in certain years. In this case, the deficit means that the demand for natural gas in Indonesia is greater than the supply of natural gas available in Indonesia. In determining production capacity, we use scenario 3 of Indonesia's gas balance because scenario 3 is the most likely scenario to occur in the future because it considers the increase in gas demand from the retail industry sector, which is expected to continue to grow in tandem with economic growth.

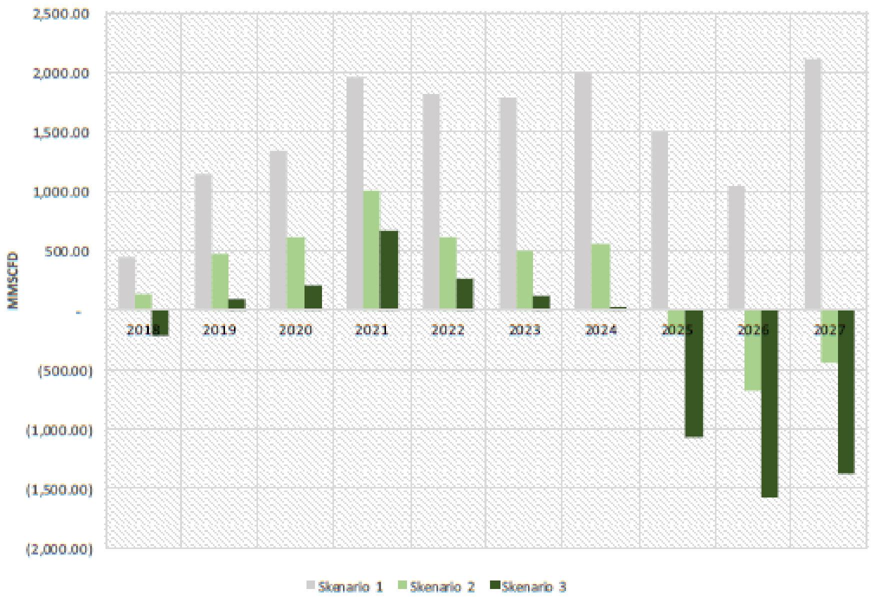

Fig. 5. Indonesia's Gas Balance [20]

With the planning that the production process begins in 2025, it can be seen that in 2025 the demand for natural gas is 1,100 MMSCFD (Million Standard Cubic Feet per Day) or approximately 8 MTPA LNG. In determining the size of the LNG plant capacity to be designed, it must clearly know the capacity of the plant that is already operating, which is usually called economic capacity. As a matter of consideration, it is necessary to know the capacity of the factory LNG offshore.

Based on Table 4, each company has a different production capacity. Indonesia itself does not yet have FLNG to process natural gas into LNG on a floating ship, but there is only an FSRU plant that functions as storage and regasification of liquefied natural gas on board a floating ship. Thus, based on the existing FLNG plant natural gas that can be produced in the well field in the Masela block of around 358 MMSCFD, it was decided that the production capacity of this LNG plant is around 2.5 MPTA with an operating time base of 330 working days/year and working time factory for 24 hours/day.

Table 4
Existing Offshore LNG Plant

Factory	LNG Production Capacity (MPTA)
Prelude FLNG (Australia)	3.6
PFLNG One (Malaysia)	1.2
PFLNG Two (Malaysia)	1.5

2.2 Floating LNG Process Description

The FLNG technology enables the production, liquefaction, storage, and transfer of LNG at sea as well as the processing and export of condensate and liquefied petroleum gas (LPG). This creates the possibility of developing gas that could otherwise be economically difficult to develop or where using a more conventional onshore LNG idea might present environmental difficulties [21]. Based on Figure 6, an Offshore LNG plant uses a ship designed as a floating facility commonly referred to as FLNG (Floating LNG). The FLNG operating system itself consists of gas conditioning and liquefaction on ships operating on the high seas, sending LNG vessels, and FSRUs.

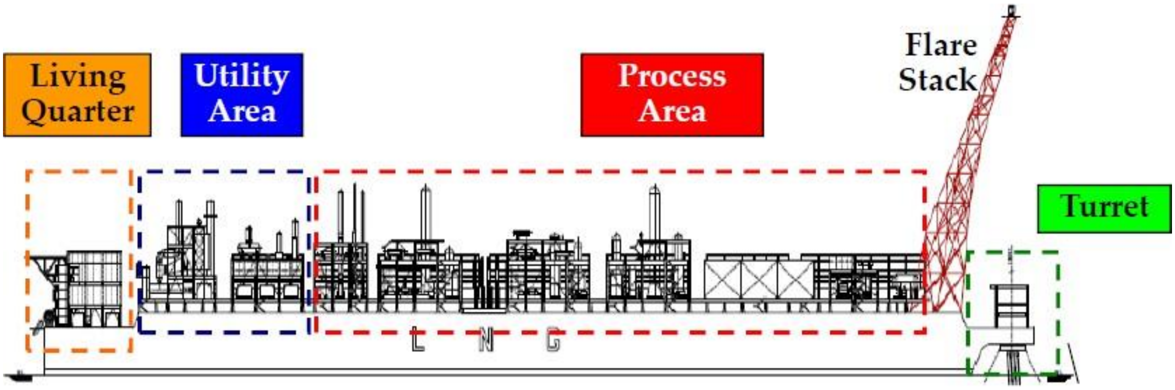

Fig. 6. Parts of Floating LNG

FLNG has several parts on the surface of the ship such as turrets, process areas, utility areas, and worker accommodation, while for the bottom of the ship or in the hull there is storage of LNG, LPG, condensate, and utilities. The LNG plant uses a series of processes based on Figure 7, such as an acid gas removal unit, dehydration unit, liquefaction unit, and refrigerant unit which will then select the appropriate process from each unit.

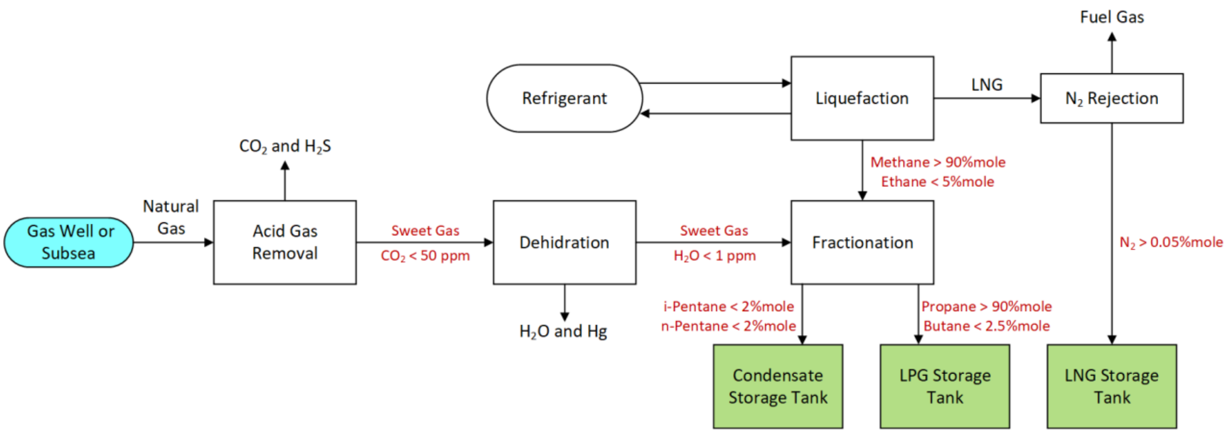

Fig. 7. Block Diagram Configuration of Floating LNG Plant

Every chemical process has a balance calculation, both mass balance and heat balance. The basic assumption used in the process is in a steady state. The mass balance calculation used is in Eq. (1).

$$m_a = m_i - m_o + m_g - m_c \tag{1}$$

m_a represents the accumulated mass, m_i is the mass entering the operating unit, m_o stands for the outlet mass from the system, m_g denotes the regenerated mass, and m_c is the mass consumed into the system. In the steady state, it is assumed that no mass is accumulated. In addition to mass balance, a chemical process also requires energy balance which is closely related to the thermodynamic state of a process. Assuming a steady state, the energy balance can be formulated as in Eq. (2).

$$\Delta H_{in} + E_{k_{in}} + E_{p_{in}} + Q = \Delta H_{out} + E_{k_{out}} + E_{p_{out}} + W_s \tag{2}$$

Where ΔH signifies enthalpy change, E_k is kinetic energy, E_p represents potential energi, Q ndicates heat flowing from the environment to the system, and W_s means work done on process fluid by a moving part or shaft work. In other assumptions, changes in kinetic energy and potential energy are ignored so that the energy balance only affects changes in enthalpy, heat, and shaft work.

2.2.1 Acid gas removal unit (AGRU)

The processing of natural gas into LNG requires the removal of acid gas or acid components from the natural gas stream through an absorber column. This process uses absorption because this process has a fairly low cost and power. The acid gas removal unit was selected to use the absorption process because it has a fairly low cost and power. The material selection will use a mixture of MDEA and MEA because it has a high absorption rate and only requires a small stage [22]. The solvent to be used is an amine mix compound of MDEA/MEA with a concentration of 40/10 because it can reduce the levels of acid components in the gas stream to 4 ppm [23]. Acid gas contained in the feed gas will be dissolved by the solvent because it has a higher solubility where the value for the molar amount of acid gas that can be taken by the solvent is around 0.2-0.80 mol acid gas/mol amine [24]. Polar functional groups on amines are chemically reactive and capable of forming strong chemical interactions with acid gas. In the top stream of the column, the gas will continue down the column towards the dehydration process. While downstream, the amine-containing acid gas (rich amine) flowed to the rich amine flash tank. In this tank, the pressure will be lowered to release dissolved gases, including acid gas that has been absorbed by the amine. This gas is then released towards the top of the tank as flue gas, while the richer amine is taken to the amine regeneration column unit to regenerate the solvent (amine) by separating the acid gas (CO_2 and H_2S) dissolved in the solvent. The configuration of acid gas removal is given in Figure 8.

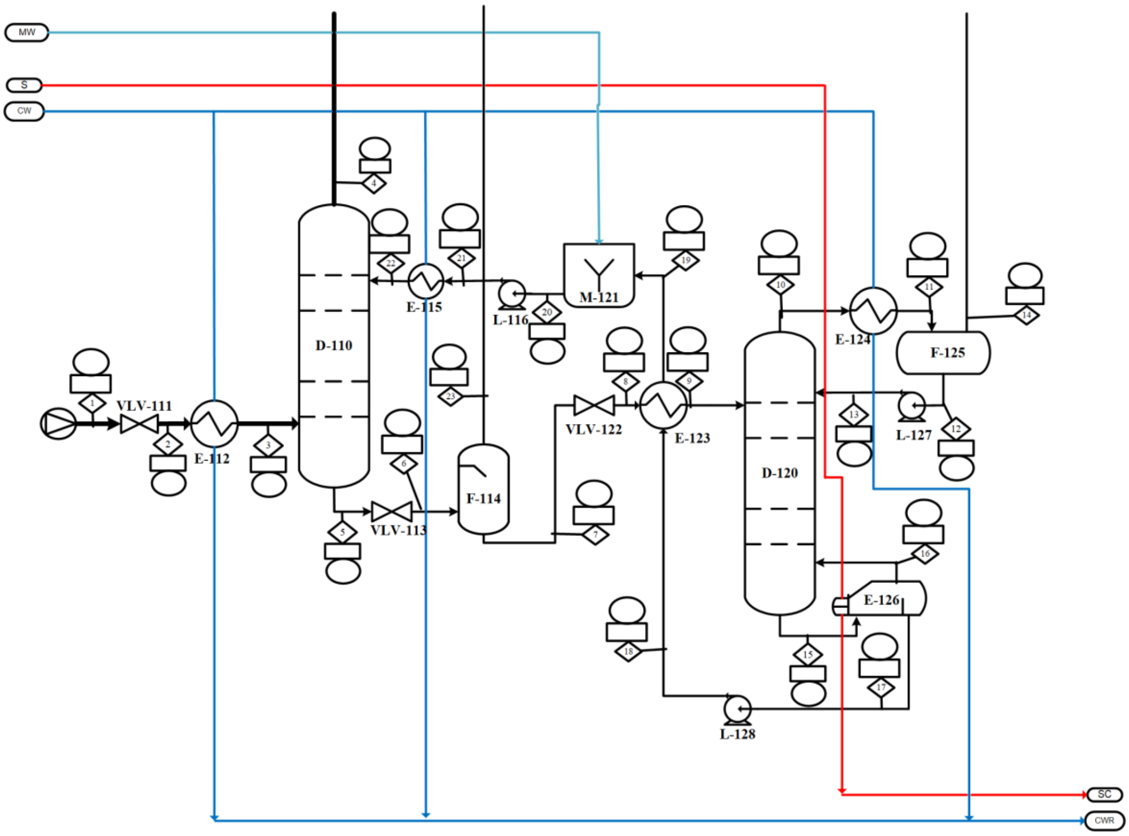

Fig. 8. Configuration of Acid Gas Removal Unit (AGRU)

2.2.2 Dehydration unit

The dehydration process aims to remove the water content contained in the feed gas. This is because the allowed water contained in the feed gas to be processed into LNG is less than 0.5 ppm. In this dehydration process using the combination of TEG and molecular sieve. An adsorption process using molecular sieve adsorbent type 3A is used because it is able to remove H_2O to a maximum limit of less than 1 ppm and has a small pore size. In addition, glycol-based absorbers can also be used in gas dehydration. Triethylene Glycol (TEG) is recommended because it is the most common material in the process. TEG also has the advantages of being easier to cool to pure conditions, optimal conditions at atmospheric temperature, having a high initial decomposition temperature, and having low capital and operating costs [25].

The first operating unit in the dehydration process is the TEG absorber. At this stage, the gas coming from the absorber column still containing water will enter the bottom of the TEG absorber column. In the column, rich TEG flows from the top and contacts with natural gas in the opposite direction. TEG absorbs water from the natural gas, reducing the water content in the gas stream. After passing through the TEG absorber, the water-rich TEG flows into the TEG regeneration column. In this column, the TEG is heated using a reboiler to remove the absorbed water. The recovered TEG descends to the bottom of the column. After the TEG exits the regeneration column, the recovered TEG and the required TEG (make-up TEG) are mixed in a mixer. Lean TEG will flow back to the TEG absorber for further dehydration process. Sweet gas is then flowed to the mixer which will be mixed with TEG recovery that has been obtained from the regeneration column.

Sweet gas feed is flowed from the top of the dehydration column and the H_2O-free gas exits from the bottom of the column. The molecular sieve used will reach a saturated state, so a regeneration process is needed to reactivate it. The column will be regenerated in turn when the molecular sieve is saturated, thus removing the water adsorbed by the molecular sieve. When a column is regenerated, one column is on standby, and the other is operating. The molecular sieve is reactivated using a small portion of the natural gas that exits the molecular sieve column. As stated study by Malek *et al.,* [26], in the catalyst reactivation process, the dehydration process generally uses a mixing-tee piping system that runs in thermal-cyclical mode. The regeneration gas is passed in the opposite direction to the dehydration process, from bottom to top. This will cause the water adsorbed by the molecular sieve to become vapor and flow along with the regeneration gas out of the upper column. Then the gas consisting of a mixture of natural gas and a little H_2O is cooled with cooling water so that the water in the gas will condense, which is then separated liquid H_2O with regeneration gas through knock-out water. Furthermore, the water obtained is disposed of as wastewater, while the gas coming out of the top of the knock-out water will be recycled back into the feed gas flow. The configuration of the dehydration unit is given in Figure 9.

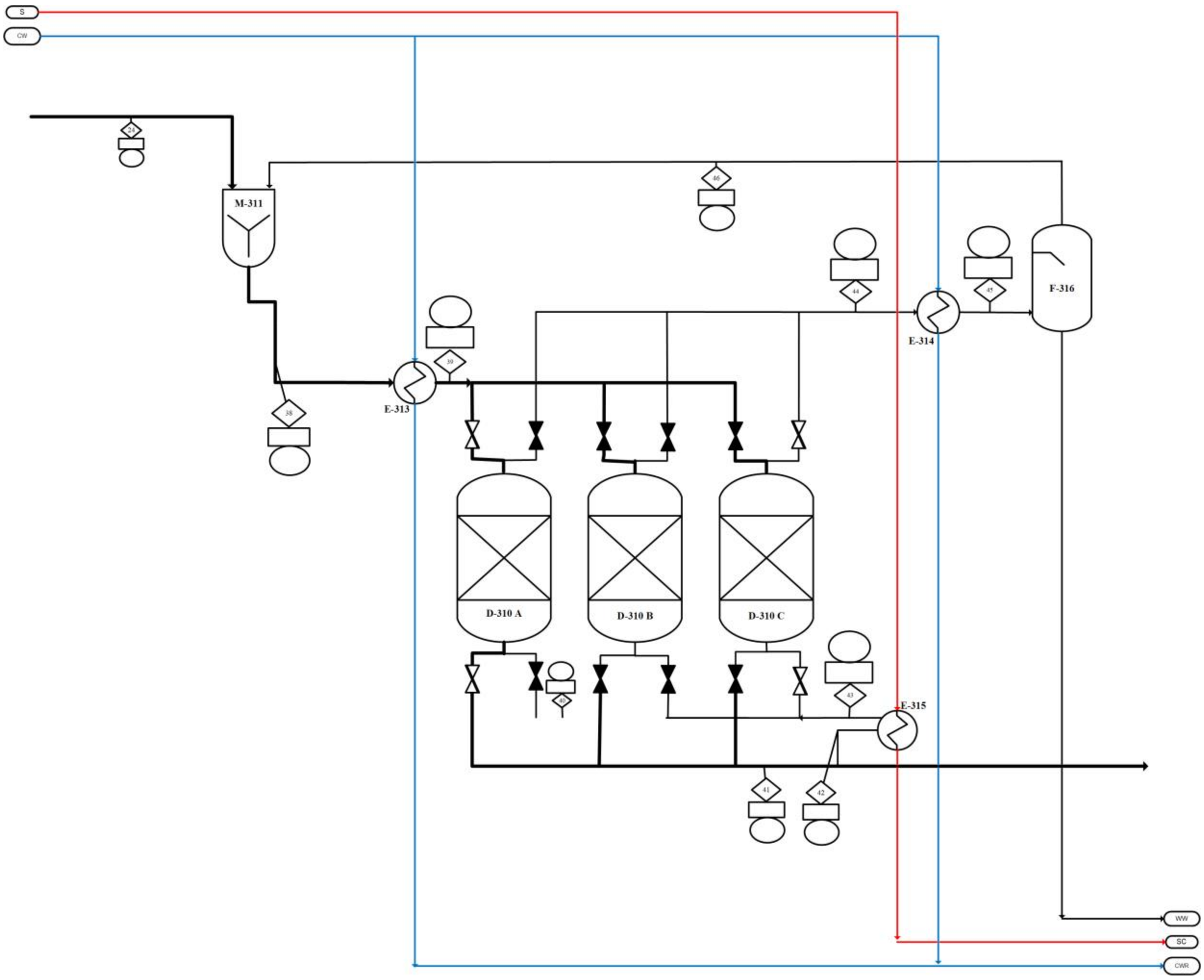

Fig. 9. Configuration of the Dehydration Unit

2.2.3 Fractionation unit

Fractionation is the process of separating a mixture of components by utilizing the difference in boiling points between components. Basically, a mixture of components is heated in a multistage distillation column to separate the components based on their different volatilities or boiling points. In a distillation column, the component mixture is fed to the bottom of the column and heated. Components that have a lower boiling point will vaporize first, rise to the top of the column, and be removed as overhead products. Meanwhile, components with higher boiling points will remain in liquid form, collect at the bottom of the column, and be removed as the bottom product.

The natural gas that has gone through the dehydration process then enters the bottom of the deethanizer column. At the same time, heat is supplied through the deethanizer reboiler to provide the necessary heat for the separation process. In the column, the components with the lowest boiling points, such as methane and ethane, will rise to the top of the column due to their lighter densities, while the heavier components will remain at the bottom of the column. The vapor rising from the deethanizer column then passes through a condenser to be cooled. The liquid is collected in the accumulator and then used as reflux. Furthermore, methane and ethane that have been separated in the column will be forwarded to the liquefaction process. Meanwhile, the components left under the deethanizer column have flowed to the debutanizer column for the separation process to continue with a similar principle as in the deethanizer column. The debutanizer column aims to separate the butane component (C4) as an overhead product with heavier fractions of natural gas that will be left at the bottom of the column. The separated butane component will flow to the storage tank as LPG product while the lower part will flow to the storage tank as the condensate product. The configuration of the fractionation unit is given in Figure 10.

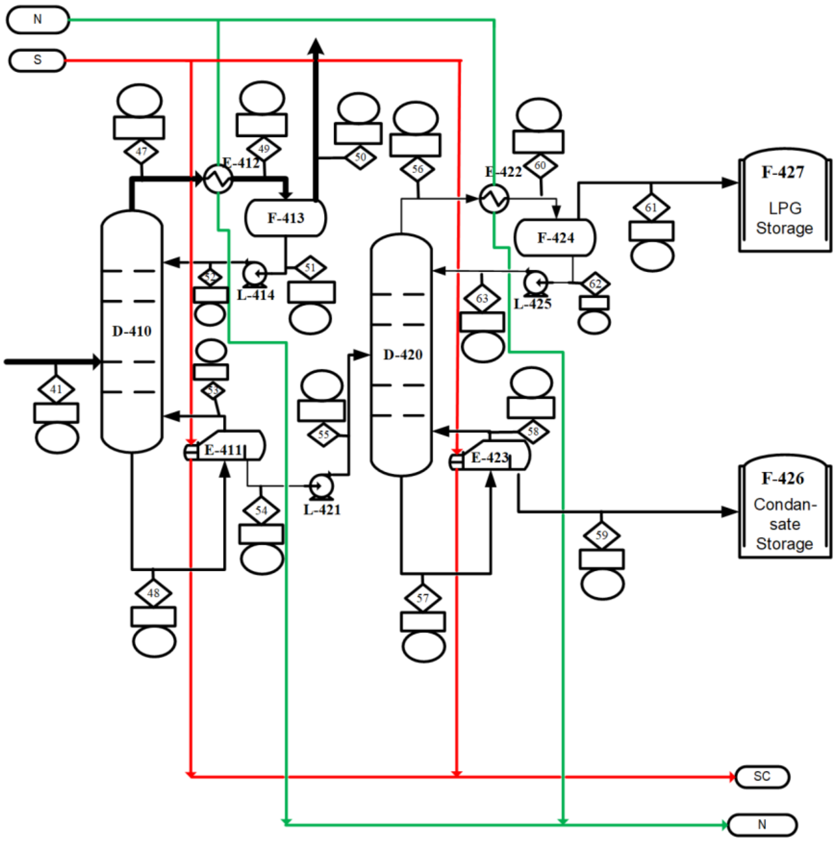

Fig. 10. Configuration of the Fractionation Unit

2.2.4 Liquefaction unit

The liquefaction process is the process of changing the gas phase of the overhead product deetanizer into a liquid phase called LNG, in this process uses a refrigeration system that has the aim of maintaining low temperatures. Common equipment in the refrigeration system consists of an evaporator or Main Heat Exchanger, compressor, condenser, and JT valve, in this LNG process the gas will be cooled using refrigerant. This process uses a Double Mix Refrigerant System (DMR) because it has a high liquefaction cycle efficiency, besides that, it also has a higher capacity when compared to the C3MR process [27,28]. A certain composition ratio in order to have a low bubble point, large heat of vaporization, and high effectiveness.

The top product gas of the deethanizer column contains a lot of methane, ethane will have flowed Pre-cooling Heat Exchanger for the first initial cooling from -6°C to -50°C using PMR (Pre-Cooling Mix Refrigerant) which will then be displayed at the exit part will be recycled back into PHE and part will be used in the second Pre-cooling which has a composition of CH_4, C_2H_6, C_3H_8, i-C_4H_{10} in a ratio of 3: 51:29:17 and MR (Mix Refrigerant) which will then be used in the 2nd Pre-cooling which has a composition of N_2, CH_4, C_2H_6, and C_3H_8. with a ratio of 29:51:17:3 [28]. Furthermore, the output gas will be cooled again at a temperature of -90°C in the second Pre-Cooling Heat Exchanger using PMR and MR output from the first Pre-cooling process, PMR at this stage will be recycled as in the first pre-cooling process which will then be inserted into the compressor with seawater or cooling water media. After that, it is cooled again using a condenser. As for the MR output at the second precooling, the phase will be separated in the MR Separator into LMR (Light Mix Refrigrant) and HMR (Heavy Mix Refrigerant) which will be used in the Main Heat Exchanger. Furthermore, the second Pre-Cooling output gas will enter the main cooling Main Heat Exchanger to convert into LNG products with a temperature of -158.2°C by using LMR (Light Mix Refrigrant) and HMR (Heavy Mix Refrigerant) which have been separated in the separator. Furthermore, the LMR and HMR outputs will be recycled back into and depressurized using the JT Valve. Then, the MR recycle output is compressed and cooled which will be reused in the first pre-cooling. As for LNG, it will be taken to N_2 Rejection to remove excess N_2 residue into the flue gas, and LNG will go to the Storage Tank. The configuration of the liquefaction unit is given in Figure 11.

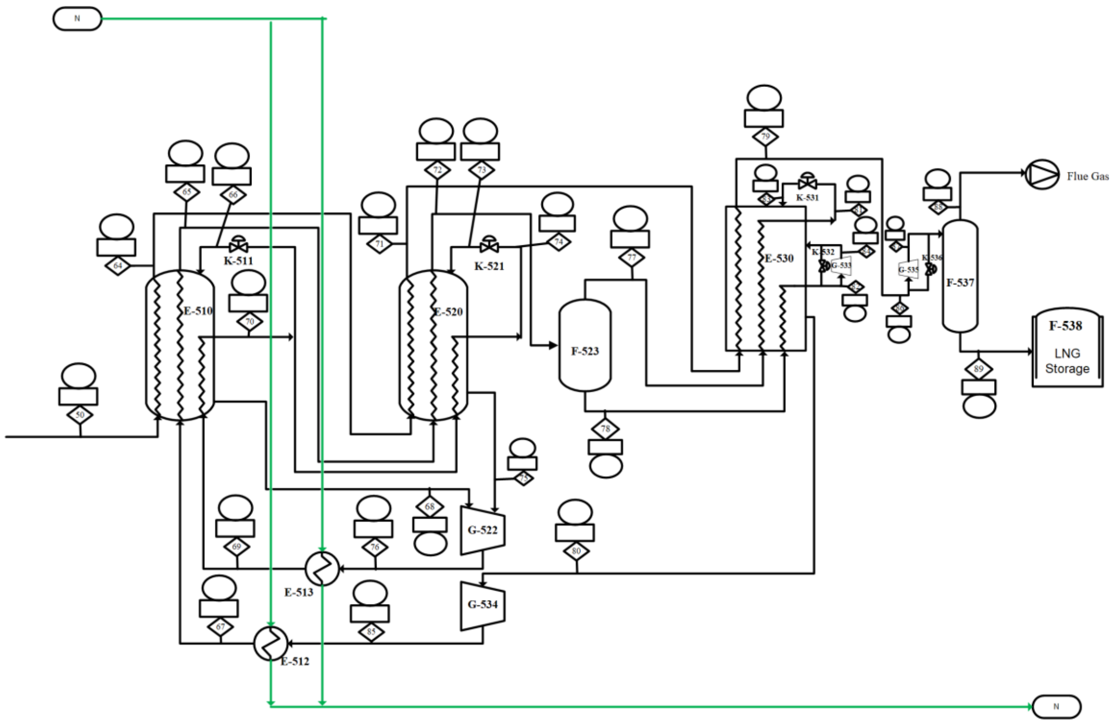

Fig. 11. Configuration of the Liquefaction Unit

2.3 Economic Analysis

Economic analysis is a crucial parameter in evaluating the feasibility of establishing a factory. Determining the economic viability of a factory necessitates calculating the raw materials required for production and the cost of the equipment utilized in the process. In addition to the parameters, assessing expenses for operations and utilities, employee salaries, and land acquisition for factories is essential [12]. The economic parameters under review include Net Present Value (NPV), Internal Rate of Return (IRR), Pay-out Time (POT), and Break-even Point (BEP). The discounted cash flow method is utilized for economic analysis, with a current estimate on the projected value. It is essential to assume the cost of the necessary materials. The basic material costs and basic economic assumptions used are as follows in Table 5.

Table 5
Economic Parameters Assumption for Floating LNG Plant

Parameters	Assumptions	Material	Value
Private Capital	20%	Natural Gas	\$2.24/MMBtu
Loan Capital	80%	LNG Product	\$6/MMBtu
Bank Interest	8%	LPG Product	\$681.8/ton
Inflation Rate	1.75%	Condensate Product	\$144.4/barrel
Income Tax	30%		
Plant Lifetime	25 years		
Construction Period	2 years		

One of the parameters used as a measure of plant feasibility is Net Present Value (NPV). Net present value is the difference between the value of cash inflows and the value of cash outflows each year. NPV is used when calculating investment capital to analyze the potential profitability of a project or investment to be made. A positive NPV value states that the projected future income of the factory will make a profit, instead if the NPV value is negative, it indicates a loss. Bagajewicz [29] has provided a formula for calculating NPV in Eq. (3).

$$NPV = \sum_{i=1}^{N} \frac{CF_i}{(1+r)^i} - I \tag{3}$$

Where CF_i is the after-taxes cash flow of the period, I the capital investment, and r is the minimum expected rate of return, also called the “opportunity cost of capital”. The engineering field also evaluates projects using various measures other than net present value, including the internal rate of return (IRR) formulated in Eq. (4).

$$I = \sum_{i=1}^{N} \frac{CF_i}{(1+IRR)^i} \tag{4}$$

The internal rate of return (IRR) provided within the solution can be viewed as the rate of return that makes the NPV equal to zero. IRR has its appeal due to the preference to look at investments in terms of percentage return on capital investment [29]. The break-even point (BEP) is a condition where selling revenue is less than variable costs and fixed expenses which results in zero profit. The place where total revenue (sales) and total expenditure intersect is represented in a graph [30]. An illustration of the break-even point determination is shown in Figure 12.

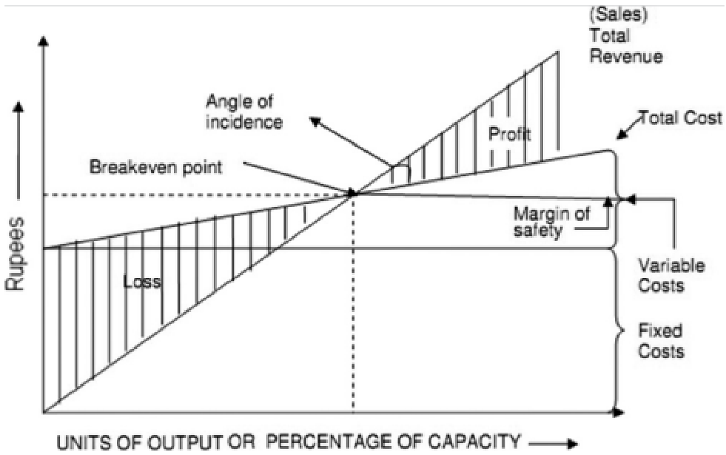

Fig. 12. Illustration of the break-even point (BEP) [30]

The break-even point is defined as the percentage of the total plant capacity that has the calculations in Eq. (5).

$$BEP = \frac{FC+P_{min}}{p-vc} \tag{5}$$

where BEP is the production volume at the break-even point, P_{min} is the profit achieved, FC is the fixed cost, p is the product price, and vc is the variable cost per piece.

3. Result and Discussion

Indonesia possesses vast natural gas reserves. However, challenges like unfriendly geographical conditions and small gas content in some sources hinder exploitation. Onshore refineries are more accessible, but the likelihood of discovering new reserves is lower since 1/3 of the world's natural gas reserves are offshore. Offshore gas production relies on pipelines to reach onshore terminals, feasible only when production is sufficient, and distances are short. To maximize natural gas utilization, offshore LNG Plants, resembling floating facilities, offer a solution like onshore terminals.

An offshore liquefied natural gas (LNG) plant utilizes a specially designed vessel that functions as a floating facility. This FLNG system comprises multiple intricate components and processes conducted at sea, primarily encompassing gas conditioning and the liquefaction of natural gas aboard these offshore vessels. The liquefied natural gas is then transported via dedicated LNG carriers and Floating Storage and Regasification Units (FSRUs) to various distribution points and markets. The concept of FLNG offers remarkable advantages, including the ability to access remote gas reserves and reduce the need for extensive onshore infrastructure. In order to present a summary of the technical and economic features of the Offshore LNG project is feasible, a preliminary study of the development plan is required.

The offshore LNG plant is planned to commence operations in 2025 with a production capacity of 2.5 MPTA. The location of the refinery is planned in the Masela block area due to the abundant and untapped availability of natural gas. The overall mass balance of this LNG plant from natural gas is as follows in Table 6 and Table 7.

Table 6
Inflow Mass Balance

Information	Mass flow rate
Natural Gas Feeds	315,128.4 kg/hour

Table 7
Mass Balance Outflow

Information	Mass flow rate	Information	Mass flow rate
LNG Products	230,768.8 kg/h	Flue gas, Acid Gas and Wastewater	78,202.7 kg/h
LPG Products	5,800 kg/h		
Condensate Products	356.8 kg/h		
Total Products	236,925.8 kg/h	Total Purge	78,202.7 kg/h
Total Exit	315,128.4 kg/h		

To meet its annual capacity, the refinery operates 24/7 for 330 days with up to 315,128 kg/hour of natural gas raw materials, producing 230,768 kg/hour of LNG, 5,800 kg/hour of LPG, and 356 kg/hour of condensate products. The offshore LNG plant's production process consists of four processes: Acid Gas Removal, Dehydration Unit, Fractionation, and Liquefaction. For acid gas removal, a MDEA and MEA mixture is utilized for absorption. Additionally, TEG and Molecular Sieve type 3A are employed to dehydrate. Deethanizer and debutanizer columns are then utilized in the fractionation process. For its own utility needs, the amount of cooling water needed is 2,867,359 kg/hour. The amount of steam needed is 167,181.4 kg/hour which can be seen in Table 8.

Table 8
List of Equipment Heat Requirements

Tool name	Tool code	Heat Requirement (kJ/h)
Amine Regenerator Reboiler	E-126	1621322
TEG Regenerator Reboiler	E-223	7239.9
Molecular Sieve Regen Heater	E-315	9581
De-etanizer Reboiler	E-411	83.8
De-butanizer Reboiler	E-423	2639.3

In this plant, the value of Capital Expenditure (CAPEX) consists of accumulation between Fixed Capital Investment and Working Capital Investment. Through the calculation of these parameters, the CAPEX value is obtained as follows in Table 9.

Table 9
Capital Expenditure (CAPEX) Parameters

Parameters	Value
Fixed Capital Investment	Rp 28,981,101,585,903
Working Capital Investment	Rp 5,114,312,044,571
Capital Expenditure	Rp 34,095,413,630,474

The value of Operational Expenditure (OPEX) consists of the accumulation between manufacturing costs and general expenses. Based on the calculation of these parameters, the OPEX value is obtained as follows in Table 10.

Table 10
Operational Expenditure (OPEX) Parameters

Parameters	Value
Manufacturing Cost	Rp 10,851,648,436,119
General Expenses	Rp 434,686,337,445
Operating Expenditure	Rp 11,286,334,773,564

Hence, to be able to establish a factory with a production capacity of 2.5 MPTA, a capital investment cost of Rp 34,095,413,630,474 is required, with estimated product sales of Rp 21,981,811,817,938 per year. For Net Present Value (NPV) calculation, the given value is Rp 8,323,106,879,243 or a positive value which means this plant is profitable to develop. The NPV value is the weighted average cost of capital (WACC) value minus the total investment value at the end of the construction period. Then, the Internal Rate of Return (IRR) parameter has been already considered. The percentage of IRR value given to 12.3% is higher than the bank interest rate which has to be assumed at 8% per year. A higher value of IRR than the yearly interest rate gives effect to more feasible investment to be realized [31]. Regarding the break-even point (BEP) analysis, it is found that the plant will start to make a profit when the minimum capacity limit of the operated plant reaches 36%, which is shown in detail in Figure 13. These results are acceptable because in principle the maximum BEP value occurs at 50% of the plant capacity which refers to the economic sustainability of plant construction.

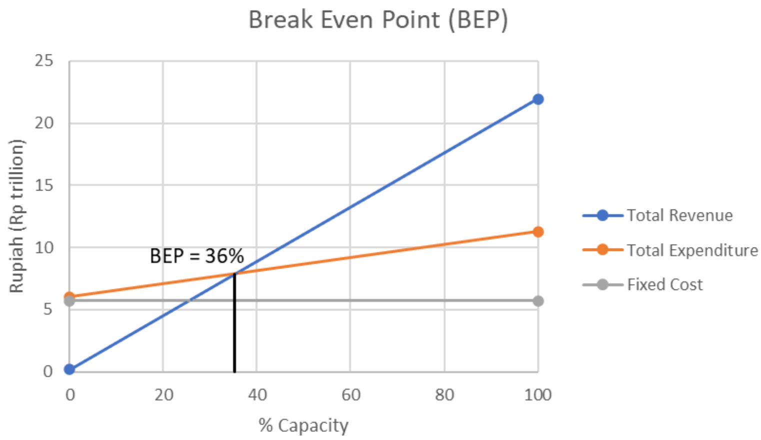

Fig. 13. The break-even point of Masela Block FLNG Plant

4. Conclusion

From the results of plant reviews that have been carried out, it can be concluded that this offshore LNG plant when viewed from a technical point of view series of manufacturing processes can achieve the desired product specifications and according to standards, both for main products and by-products. Based on the selection of the technology for each unit in the Floating LNG Plant, that is for an acid gas removal unit (AGRU) using an absorption method with MDEA/MEA solvent due to high absorption rate and only requires a lower stage. Then, usage of the dehydration unit can utilize TEG absorption based on low cost and optimal conditions in atmospheric and Molecular Sieve type 3A due to the small pore for the effectiveness of eliminating hydrate. For the liquefaction unit, choosing a double-mix refrigerant System (DMR) is recommended because of its high liquefaction cycle efficiency and higher capacity. From an economic point of view, the IRR obtained at 12.3% is above the bank loan interest rate, which is 8% with a payback period (POT) of 4.81 years, which is smaller than the repayment time set by the lender which is 10 years, and break-even point (BEP) has reached

36% that just acceptable which refers to the economic sustainability of plant development. Therefore, offshore LNG plants are feasible to be established with low investment and high profit.

Acknowledgment
This work was supported by KEMENDIKBUDRISTEK under the Hibah Penelitian Tesis Magister (PTM) number: 112/E5/PG.02.00.PL/2023 and DRPM Institut Teknologi Sepuluh Nopember number: 2009/PKS/ITS/2023.

References

[1] Mokhatab, Saeid, John Y. Mak, Jaleel V. Valappil, and David Wood. *Handbook of liquefied natural gas*. Gulf Professional Publishing, 2013.
[2] Mokhatab, Saeid, William A. Poe, and John Y. Mak. *Handbook of natural gas transmission and processing: principles and practices*. Gulf Professional Publishing, 2018. https://doi.org/10.1016/B978-0-12-815817-3.00015-0
[3] Bukowski, Justin D., Yu Nan Liu, M. R. Pillarella, S. J. Boccella, and William A. Kennington. "Natural gas liquefaction technology for floating LNG facilities." *IGRC, Seoul* (2013).
[4] Ministry of Energy and Mineral Resources of Indonesia. "Oil and gas statistics semester 1." *Ministry of Energy and Mineral Resources of Indonesia*, 2021.
[5] Vieira, Daniel Prata, Rodrigo Sauri Lavieri, Thiago Peternella Rocha, Raul Dotta, Fabiano Rampazzo, and Kazuo Nishimoto. "A synthesis model for FLNG design." In *International Conference on Offshore Mechanics and Arctic Engineering*, vol. 49927, p. V001T01A015. American Society of Mechanical Engineers, 2016. https://doi.org/10.1115/OMAE2016-54983
[6] Anugraha, Rendra Panca, Renanto Handogo, Ali Altway, Juwari Purwo Sutikno, Muhammad Fakhrizal Fahmi, Rizal Arifin, and Vibianti Dwi Pratiwi. "Optimization of Process Economics in Mini Oil Refinery for Remote Areas." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 102, no. 1 (2023): 14-24. https://doi.org/10.37934/arfmts.102.1.1424
[7] Handogo, Renanto, Fery Prasetyo, Santi Puspita Sanjaya, Annasit Annasit, and Rendra Panca Anugraha. "Preliminary design of mini oil refinery plant." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 92, no. 1 (2022): 39-50. https://doi.org/10.37934/arfmts.92.1.3950
[8] Nasrudin, I., and C. S. M. Syafiqiuddin. "Design study of power management system for parallel operation of generator set of a ship's diesel electric power plant." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 20, no. 1 (2016): 1-11.
[9] Finn, Adrian J. "Effective LNG production offshore." In *81st Annual GPA Convention*, pp. 10-13. 2002.
[10] Agosta, A., D. Dediu, and B. Heringa. "Global Gas Outlook to 2050." *McKinsey & Company: Brussels, Belgium* (2021).
[11] Lee, Sanggyu, Nguyen Van Duc Long, and Moonyong Lee. "Design and optimization of natural gas liquefaction and recovery processes for offshore floating liquefied natural gas plants." *Industrial & Engineering Chemistry Research* 51, no. 30 (2012): 10021-10030. https://doi.org/10.1021/ie2029283
[12] Giranza, M. J., and A. Bergmann. "An economic evaluation of onshore and floating liquefied natural gas receiving terminals: the case study of Indonesia." In *IOP Conference Series: Earth and Environmental Science*, vol. 150, no. 1, p. 012026. IOP Publishing, 2018. https://doi.org/10.1088/1755-1315/150/1/012026
[13] Khoiriyah, Lilik, Ketut Buda Artana, and A. A. B. Dinariyana. "Conceptual design of floating storage and regasification unit (FSRU) for Eastern Part Indonesia." In *IOP Conference Series: Earth and Environmental Science*, vol. 1239, no. 1, p. 012015. IOP Publishing, 2023. https://doi.org/10.1088/1755-1315/1239/1/012015
[14] He, Tianbiao, Zuming Liu, Yonglin Ju, and Ashak Mahmud Parvez. "A comprehensive optimization and comparison of modified single mixed refrigerant and parallel nitrogen expansion liquefaction process for small-scale mobile LNG plant." *Energy* 167 (2019): 1-12. https://doi.org/10.1016/j.energy.2018.10.169
[15] Rufford, Thomas E., Simon Smart, Guillaume C. Y. Watson, B. F. Graham, John Boxall, J. C. Diniz Da Costa, and E. F. May. "The removal of CO_2 and N_2 from natural gas: A review of conventional and emerging process technologies." *Journal of Petroleum Science and Engineering* 94 (2012): 123-154. https://doi.org/10.1016/j.petrol.2012.06.016
[16] Ciahotný, Karel, Tomáš Hlinčík, Alice Vagenknechtová, and Ondřej Prokeš. "Adsorbents for the natural gas drying at CNG stations." *Acta Montanistica Slovaca* 21, no. 4 (2016).
[17] Smulski, Rafał, and Jarosław Sacha. "The dependency on the temperature of efficiency of the regeneration process in glycols." *AGH Drilling, Oil, Gas* 33, no. 4 (2016). https://doi.org/10.7494/drill.2016.33.4.733
[18] Badak LNG. "Badak Handout: LNG Technology (Floating LNG)." *Badak LNG*, 2007.
[19] Yerido, Hezron, Hadi Wiratama, Gede Wibawa, and Kuswandi Kuswandi. "Pra Desain Pabrik Floating LNG Di Blok Masela." *Jurnal Teknik ITS* 4, no. 2 (2016): B99-B102.

[20] Ministry of Energy and Mineral Resources of Indonesia. "Indonesia's Natural Gas Balance 2018-2027." *Ministry of Energy and Mineral Resources of Indonesia*, 2018.

[21] Boekhorst, Alexander, Bruce Steenson, and Harry van der Velde. "FLNG: Applying Advanced Technology to bring more natural gas to market." In *Offshore Technology Conference*, pp. OTC-25907. OTC, 2015. https://doi.org/10.4043/25907-MS

[22] Qayyum, Aeman, Usman Ali, and Naveed Ramzan. "Acid gas removal techniques for syngas, natural gas, and biogas clean up-a review." *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects* (2020): 1-24. https://doi.org/10.1080/15567036.2020.1800866

[23] Abdulrahman, R. K., and I. M. Sebastine. "Natural gas sweetening process simulation and optimization: A case study of Khurmala field in Iraqi Kurdistan region." *Journal of Natural Gas Science and Engineering* 14 (2013): 116-120. https://doi.org/10.1016/j.jngse.2013.06.005

[24] Gas Processors Suppliers Association (GPSA). "GPSA Engineering Data Book." *Tulsa, OK, USA* (2012).

[25] Manning, Francis S., and Richard E. Thompson. *Oilfield processing of petroleum*. PennWell Books, 1991.

[26] Malek, Abdul Matin Al-Barr, Abdul Rahim Othman, and Muhammad Firdaus Othman. "A Computational Technique for Low-Cycle Fatigue of LNG Mixing-Tee Weldment-An Industry Case Study." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 104, no. 2 (2023): 103-114. https://doi.org/10.37934/arfmts.104.2.103114

[27] Ma, Guo-guang, Chen Zhang, Yi-ran Ding, and Bo-cheng Li. "A study on the use of dual mixed refrigerant in a cascade dual mixed refrigerant cycle." *Advances in Mechanical Engineering* 9, no. 6 (2017): 1687814017710582. https://doi.org/10.1177/1687814017710582

[28] Khan, Mohd Shariq, I. A. Karimi, and Moonyong Lee. "Evolution and optimization of the dual mixed refrigerant process of natural gas liquefaction." *Applied Thermal Engineering* 96 (2016): 320-329. https://doi.org/10.1016/j.applthermaleng.2015.11.092

[29] Bagajewicz, Miguel. "On the use of net present value in investment capacity planning models." *Industrial & Engineering Chemistry Research* 47, no. 23 (2008): 9413-9416. https://doi.org/10.1021/ie071008l

[30] Kampf, Rudolf, Peter Majerčák, and Pavel Švagr. "Application of Break-Even Point Analysis." *NAŠE MORE: znanstveni časopis za more i pomorstvo* 63, no. 3 Special Issue (2016): 126-128. https://doi.org/10.17818/NM/2016/SI9

[31] Zakia, Zakia, Meylis Safriani, Nessa Radianica, and M. Faisi Ikhwali. "Economic Feasibility Study on The Development of Irrigation Channels." *International Journal of Engineering, Science and Information Technology* 2, no. 1 (2022): 131-138. https://doi.org/10.52088/ijesty.v2i1.217