A Solution to Increase Natuna D Alpha's Resource Utilization by Cryogenic Distillation: Conceptual Design & Sensitivity Study

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Abstract: Natural gas extracted from its respective reservoir needs to be processed to meet the specifications of sales gas. CO_2 is one of the components that needs to be separated from natural gas. The CO_2 concentration of natural gas varies from a content of less than 20 mole % to more than 80 mole%. There is a problem when the content of CO_2 is very high so it is necessary to modify the CO_2 level reduction by modifying the equipment or changing the operating conditions to meet the desired CO_2 purity. In this study, field conditions and characteristics reviewed is East Natuna Gas Field which has a gas composition of 71% CO_2 and 29% methane with modified pressure based on the capability and capacity of available equipment. From the conditions and characteristics of the field, the CO_2 method of separation from natural gas using cryogenic distillation was chosen.This research presents analysis and sensitivity of technical parameters that influence the method of CO_2 separation from natural gas using cryogenic distillation. The sensitivity is done by changing parameters of pressure and very high feed gas flow rate into the column. In addition, the calculation of the diameter and height of the distillation column using the calculation of the formula and the results of the simulation using commercial process flow software. This study applies a CO_2 separation process with cryogenic distillation and the desired product specification of CH_4 is 99%. The design of the equipment was simulated using two distillation columns with operating pressure at the first distillation column of 45 bar and the temperature of 19.19 oF, and for the second distillation column the operating pressure was reduced to 35 bar. The results are for the 8000 MMSCFD flow rate case obtained the first number of columns as many as 16 with the size of 7.4 meters diameter and 17.66 meters high, while the number of second column of 4 with the size of 8 meters diameter and 22.38 meters high. The results presented are still less suitable with the conditions in the East Natuna Gas Field because offshore constrains so need to be studied further for design and other methods in application in the field.

1 INTRODUCTION

Natural gas is one of most the important energy sources in the world. Today humans use natural gas to meet energy needs, where the use of gas is estimated to increase by 1.5% each year (IEA, 2017). Global gas demand for natural gas increased from 3635 bcm in 2016 to more than 5300 bcm in 2040 (IEA, 2017) Indonesia is one of the archipelagic countries that has large gas reserves spread across several regions, one of which is the East Natuna Block. Natuna Timur block is one of the gas fields that has an abundant source of gas reserves, which makes Natuna the largest undeveloped gas reserve in Southeast Asia (Fenter et al., 1996). However, the abundant potential of gas reserves also has a very high CO_2 gas content so that CO_2 separation technology is needed so that the gas produced can be utilized properly. Impurities such as CO_2, H2S, and other acid gases need to be removed from natural gas because in the presence of water, this content can make pipes and other tools corroded(Rufford et al., 2012).

At present, various methods of acquisition and technology have been implemented to increase natural gas production. The existing technology is adjusted to the field conditions and characteristics. One challenge that is often faced is the presence of acid gas contained in it. Sources of acid gas are natural gas resources that contain most of CO_2 and/ or H2S (Burgers et al., 2011). The separation process can be designed to overcome differences in molecular properties or thermodynamic properties and the .

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displacement of components in the mixture (Rufford et al., 2012). Therefore several methods of separation of acid gas have been developed, or commonly called sweetening gas processes for H2S separation, such as absorption, adsorption, membrane and cryogenic methods, each of which is used for different properties and conditions of fluid and field. In this study, the selection of CO_2 separation method with reference characteristics from the East Natuna Gas Field was carried out and a process simulation was carried out to obtain the results of the high CO_2 content separation by observing the effect of pressure and the feed rate from CO_2 gas was very high.

Natuna Gas Field is located in Indonesian waters precisely in the Natuna Sea. This field is 140 miles northeast of the Natuna Islands and 218 miles northwest of the island of Borneo. The water depth of this field is around 475 feet. The amount of gas volume in the reservoir is estimated at 222 TSCF with the composition of the gas contained among others 71% CO_2, 28% methane and heavy diffraction hydrocarbons, 0.5% H2S, and 0.5% N2 (Fenter et al., 1996). The Natuna Gas Location Map is shown in Figure 1.

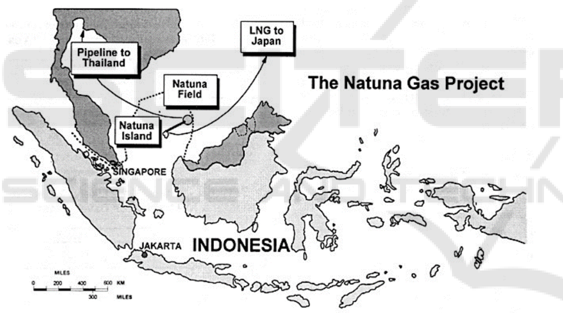

Figure 1: Location of Natuna Field (Fenter et al, 1996).

Natuna gas reservoir is interpreted in the form of carbonate domes which are isolated and contained in the Miocene Reef Formation (Fenter et al., 1996). If the formation is a carbonate formation, calcite dissolution will form CO_2. The high CO_2 content in the Natuna gas reservoir is estimated to be the result of the calcite dissolution process (Suarsana et al., 2010). This reservoir has a pressure of 5717 psig and a temperature of 340 F which is measured by measuring the well at the central depth. The estimated gas yield from this field is 75% with recoverable hydrocarbon gas of 46 TSCF (Fenter et al., 1996).

Natuna Field Reservoir contains more CO_2 than hydrocarbons. CO_2 dominates the aging of the reservoir phase and controls the production method. Because this reservoir fluid contains more hydrocarbon components, this reservoir is considered a non-hydrocarbon reservoir (Suarsana et al., 2010).

2 OVERVIEW OF NATURAL GAS-CO_2 SEPARATION PROCESS

During the requirement of separating CO_2 from natural gas, not all available methods can be applied in every field. Considerations of methods available on separating high levels of CO_2 is important so that the selection of the right method will give good results. In addition, differences also depend on the thermodynamic and transport properties (interphase), in which case the properties considered include vapor pressure, boiling point, solubility, adsorption capacity, and diffusivity (Rufford et al., 2012). Based on the nature of the components to be separated, the main operation in the gas separation and purification mechanism follows the mechanism: (1) phase formation by heat transfer and / or shaft work into or from the mixture, (2) absorption on liquid sorbents or solids, (3) adsorption on solids, (4) permeation through a membrane, and (5) changes in chemical compounds into other compounds (Kohl and Nielsen, 1997)(Seader et al., 1998). The direct chemical change in CO_2 which is currently under study is an example of dry reforming process, namely CO_2 reacts with CH_4 to form syngas (mixture of H2 and CO_2) which can later be used to produce liquid fuel through a Fischer-Tropsch reaction (Rufford et al., 2012) Then the selection for selecting an acid gas treating process can be viewed from the gas partial pressure, based on references from Aden (Nexant, 2011) and shown in Figure 2.

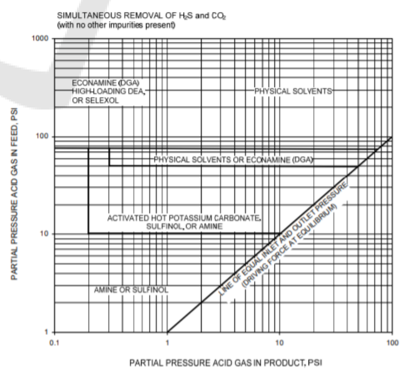

Figure 2: CO_2 Removal Chart Based on Partial Pressure (Aden, 2009).

Based on the results of Revolin's (2016) research, the selection of the CO_2 method can be done with the help of the separation process selection diagram shown in Figure 10. In addition, in this thesis a selection of CO_2 separation methods was carried out with references from (Rufford et al., 2012) based on several influential parameters in Table 1. In this study, the factors that were considered to be the most influential in the process of selecting CO_2 separation methods from natural gas include:

- The presence or absence of H_2S gas content
- Concentration of feed gas CO_2
- Feed gas flow rate
- The purity of CH_4 and CO_2 products

From the Natuna Field case, there are several characteristics that are owned as consideration of the choice of methods including:

- The H_2S content is small
- The concentration of the gas content is 29% methane and 71% CO_2
- Flow rate is very high (more than 1 BSCF, depending on the duration of the contract)
- The desired purity of the product is at least 95% methane, in this case it is targeted to be 99%.

From the parameters of CO_2 inlet concentration above 50%, then based on a summary of the technological characteristics in Table 1 that may be used are membrane technology, absorption with amine, and cryogenic distillation. Then the selection process is also carried out with the help of a selection diagram in Figure 3 with the results of technology suitable for use, namely cryogenic absorption and distillation. In this study, membrane technology and absorption were not chosen because there were several considerations based on (Rufford et al., 2012). Membrane technology requires pretreatment processes to remove heavy liquids or hydrocarbons because it can cause damage to membranes and blockages. Membrane quality depends on permeability and selectivity that cannot be obtained simultaneously. In addition, membranes are sensitive to feed conditions and hydrocarbon loss is also higher than other technologies. In the absorption method another unit is needed to regenerate solvents in the process of CO_2 gas separation. In this method it is also often formed loading, foaming, and channeling so that mass transfer is not good. Then, the absorption method requires a large amount of solvents to separate the volume of high CO_2 gas, which makes energy consumption also higher especially for regenerating solvents. Conformity between the characteristics of the cases and categories in this study resulted in the selection of cryogenic distillation.

In this study the simulation of CO_2 separation using the cryogenic distillation method was carried out using the Aspen Hysys V10 software. Simulation of CO_2 separation was carried out by applying reference to the cryogenic distillation process by Pellegrini

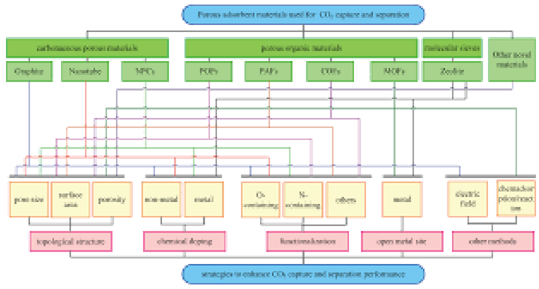

Figure 3: CO_2 Separation Guideline (Liu et al., 2015).

(Pellegrini et al., 2015) with simplification of one distillation column and reference from Revolin (2016) as a simulation baseline with several assumptions used in the process including simplified feed gas components in the form of binary mixture namely CO_2 and methane, and the vapor and liquid phases are considered ideal. The scheme of the distillation process can be seen in Figure 4.

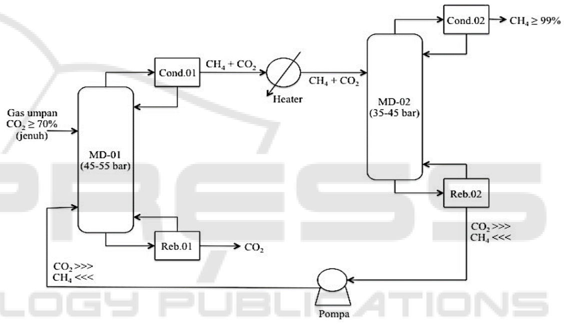

Figure 4: Cryogenic CO_2 Separation (Pellegrini et al., 2015).

In this CO_2 separation simulation the most important component observed is the distillation column. The distillation design process consists of designing processes and mechanical design. Simulation with shortcut distillation is used in the design process to find out the mass balance and the variables needed. Then, some parameters generated from this simulation that are needed for mechanical design include pressure and temperature on the top product (in the condenser) and the bottom product (in reboiler) needed, the minimum and actual stage number, the position of the feed gas stage, and reflux ratio early. In this stage data on composition, pressure, temperature, and feed gas flow rate are needed, as well as the specifications of the condenser output and reboiler needed. The feed gas flow rate obtained also makes the flow rate data for each component in the feed known.

In mechanical design, rigorous methods are used (with the distillation column) for more detailed and detailed simulations to determine and determine the profile of pressure and temperature in each stage, condenser and reboiler condition profiles, and the composition of CO_2 and methane from separation. It is necessary to know the variables needed in the distillation column, including the composition and flow rate of the feed gas, the pressure and temperature of the feed gas, the position of the feed gas stage, the number of stages and the pressure profile, and the specifications of the desired product or product. Some of the assumptions used in the distillation column include each plate in the column having an equilibrium with constant pressure reduction with a rule of thumb of 0.2 psi per plate. The pressure and temperature of the feed gas entering the distillation column need to be adjusted to match the column operating conditions. The high CO_2 content is cooled to a certain temperature and pressure on the distillation column so that the CO_2 concentration decreases to the desired level, which increases the concentration of methane. Pressure and temperature specifications are important factors that influence gas separation(Suarsana et al., 2010). The column operating conditions are assumed to be in ideal conditions or in the sense that the amount of feed gas to the distillation column is equal to the number that exits the column. Then the separation simulation is carried out using two stages of design with several sensitivity studies that refer to a predetermined base case condition.

From the base case that has been determined, pressure sensitivity and the rate of gas feed production are carried out into the distillation column. After a simulation and sensitivity study, the reflux ratio results and the number of stages needed to obtain the desired criteria for the methane and CO_2 content are obtained. Variations in the condition of the feed gas are carried out with the condition of the condenser and the reboiler being fixed.

3 CASE STUDY

Before the sensitivity study, a base case was simulated with a composition of 71% CO_2 and 29% CH_4, feed gas flow rate of 8 BSCFD, pressure of 652.7 psia, and temperature of 19.19 oF (at the dew point point) with the result specifications in the CH_4 condenser with purity of $\geq 95\%$ and the result of reboiler $CH_4 \leq 0.001\%$. From the variable reference shortcut distillation method obtained, the minimum number of stages required is 9,643 with rounded up to 10 stages, the actual number of stages is 17, and the feed gas flow is optimal in the second stage. Then the results of the condenser namely CH_4 composition has a flow rate of 2,442 BSCFD and from the reboiler obtained a flow rate of 5,558 BSCFD. The shortcut distillation operation scheme in the base case can be seen in Figure 5.

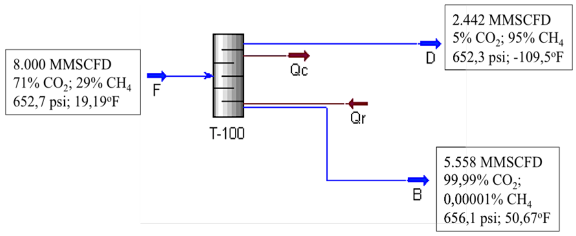

Figure 5: Cryogenic CO_2 Separation (Pellegrini, 2014).

The results of the number of stages and reflux ratios obtained from the shortcut distillation simulation are entered into the distillation column for rigorous distillation simulation and the results for this base case condition are reflux ratios of 12.08. Comparison of reflux ratio calculations with the shortcut distillation method and rigorous distillation gives different values. This is due to the rigorous distillation simulation, the calculation is done in more detail and detail that considers many variables and results until the design of column sizes. The results obtained are in the form of a static plant simulation and even dynamic if added to the addition of controls (Biyanto, 2007). While the distillation shortcut is still a rough calculation or not done in detail. The CO_2 separation scheme uses rigorous distillation in the base case distillation column attached to Figure 6.

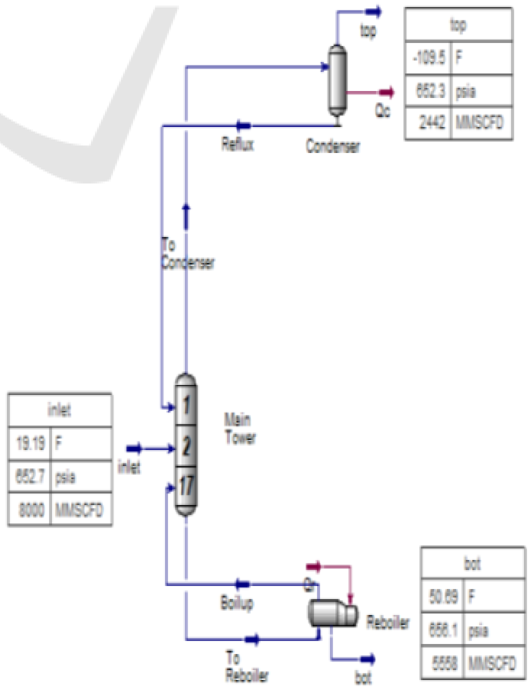

Figure 6: Cryogenic CO_2 Separation (Pellegrini, 2014).

Then a sensitivity study is carried out by reviewing the variable pressure and feed gas flow rate. The temperature conditions of the feed gas, gas specifications produced, and variations in flow rates are made the same in each case. The feed gas flow rate and the flow rate of the separation results for each rate are shown in Table 1.

Table 1: Gas Flow Rate on Distillation Column.

Flow Rate (MMSCFD)		
Feed Gas	Condenser (Top)	Reboiler (Bottom)
8000	2442	5558
1000	305.2	694.8
2000	610.4	1389.6
3000	915.6	2084.4
4000	1221	2779
5000	1526	3474
6000	1831	4169
7000	2136	4864

From Table 2, the flow rate of CH_4 generated from the condenser is smaller than the flow rate of CO_2 generated from the reboiler because the fraction of the CO_2 component in the feed gas is greater than CH_4. And also in this study, the calculation in the simulation uses the assumption of a 100% efficiency level in the separation process so that the total flow of the feed gas entering is equal to the amount that comes out. The following are the operating conditions of the distillation tower for each case shown in Table 2.

Table 2: Gas Condition in Distillation Column.

Case	Operating Condition		
	Feed Gas	Condenser	Reboiler
Base	P = 652.7 psi T =19.19 F	Pcond = 652.3 psi Tcond = -109.5 F	Preb = 656.1 psi Treb = 50.67 F
Case 1	P = 507.6 psi T =19.19 F	Pcond = 507.2 psi Tcond =-120.9 F	Preb = 510.2 psi Treb = 33.3 F
Case 2	P = 362.6 psi T =19.19 F	Pcond = 362.4 psi Tcond = -130.1 F	Preb = 364.6 psi Treb = 33.3 F
Case 3	P = 217.6 psi T =19.19 F	Pcond = 217.4 psi Tcond =-140 F	Preb = 219.4 psi Treb = -17.5 F
Case 4	P = 72.52 psi T =19.19 F	Pcond = 217.4 psi Tcond = -163.3 F	Preb = 73.92 psi Treb = -69.13 psi

In terms of operating conditions, the pressure on the condenser needs to be made smaller than the reboiler pressure. This is so that the steam formed can rise to the top of the column, according to the principle of fluid flow that the gas will flow from high pressure to low pressure.

From the sensitivity results obtained that the greater the pressure of the feed gas into the distillation column, with the same flow rate and temperature of the feed gas, the more reflux ratio is needed. This is because with high pressure the more steam formed. Even though the reflux system is condensing steam, so if the steam is high then the reflux ratio is also high. This applies also with the increasing pressure of the feed gas, the greater the number of stages needed. The principle of the stage is to separate the components in the gas feed, if the pressure is high then the interaction of the gas component is also higher, then more stages will be needed for the separation process. In this study the magnitude of the feed gas flow rate does not directly affect the magnitude of the relux ratio and the number of stages. For each case carried out, the value of reflux ratio and the number of stages are the same, but the magnitude of the feed gas flow rate affects the diameter of the distillation column more and the energy needed, in this case the condenser duty and reboiler duty. The greater the feed gas flow rate, the greater the dimension (diameter and height) of the distillation column and the energy needed. This is because a large flow rate requires a large capacity.

After the sensitivity to the influential parameters it was found that in distillation using distillation is strongly influenced by pressure and rate feed gas flow. The smaller the condenser duty feed gas pressure and the reboiler duty is also greater, but it needs to be adjusted again with the existing capacity. In the low temperature process carried out on the separation of the natural gas flow with high CO_2 concentration the cooling cycle is required in the process. In this condition, electrical energy needs are one of the important factors because they are needed in the cooling cycle. Therefore it would be better to choose the lowest pressure energy conditions, especially in this study the condenser and reboiler. From the results of the sensitivity obtained the selection of pressure is taken at the greatest value. In this study the pressure was in the range of 5-45 bars. In this study cryogenic distillation was not carried out by a higher pressure review because of the limitation of temperature determination of 19.20 F and the feed gas vapor fraction 1 which could be achieved with higher pressure when the temperature was also raised. Therefore it was chosen, the feed gas pressure was 45 bar in this study.

The design of the CO_2 separation process in this study used the method in the Pellegrini (Pellegrini et al., 2015) patent with separation using two distillation columns. The feed gas pressure entering in the first column is 45 bar and in the second column 35 bar. The purity results obtained in this study were 99% CH_4 at the end of the second column. From the first column to the second column a heater and valve are given to reduce pressure. Then the output of CO_2 in the second column is pumped back to the first column for re-separation. The design of this process can be seen in Figure 7.

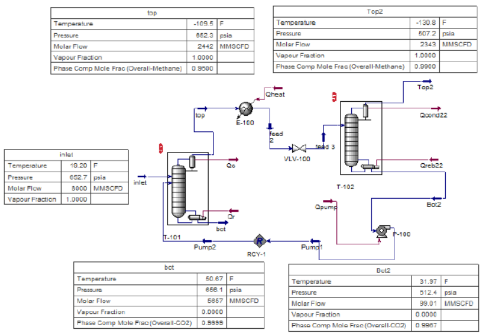

Figure 7: Overall Design of Cryogenic Process.

To validate the results of the calculation of the distillation column, a reference is needed for comparison. In this study a reference to the size of the distillation column from the RCC Regenerator Column was used, Balongan refinery with a diameter of about 9 meters and a height of more than 20 meters. Then the feed gas rate is determined by the length of the agreed contract. In this study the reference of feed gas flow rate uses a reference from Nainggolan (2016) with a flow rate of 8 BSCFD. From these references, determining the size of the distillation column can be done.

The variation in flow rate from 1-8 BSCFD produces a diameter of more than 11 meters. Whereas the flow rate of 100-800 MMSCFD has the largest diameter at the rate of 800 MMSCFD with a value of 10 meters. For the rate of 8 BSCFD, a diameter of 52.5 meters is produced, in the field this condition is not possible so there is a need for a scenario to divide the flow rate in the column in parallel, more than one in each column. In the first column the maximum rate that can be accommodated is 500 MMSCFD with a diameter of 7.4 meters, while for the second column the maximum rate that can be accommodated is 610.4 MMSCFD from the results of the first column with a diameter of 8 meters. The scenario is based on the smallest condenser duty and reboiler duty total requirements is selected so that the first scenario with column 1 (7.4 meters in diameter and 17.66 meters in height) is obtained and 16 pieces are needed column 2 (with a diameter of 8 meters and a height of 22.38 meters) requires 4 pieces. From these results for the next process, it is necessary to consider the application of the distillation column in the field, with the limitation of the location of the Natuna Gas Field which is offshore resulting in the availability of land and installation of the distillation column equipment that needs to be reviewed.

Based on the designs presented above, it can be proposed to be two main distribution/processing hub, namely the platform based unit processing and onshore facility, connected with underwater pipeline. It is worth noting that applying platform based processing facility requires massive capital due to the size of the processing facility, while using onshore facility would require very large pipe with high corrosion potential. Further study should be done to assess the economic and technical feasibility of these projects.

4 CONCLUSIONS

The choice of CO_2 separation technology from natural gas is based on several factors that are highly dependent on the conditions and characteristics of the gas field being reviewed.

Under pressure and gas flow rates based on the case of the Natuna Gas Field, the cryogenic distillation process is chosen in the separation of CO_2 content at high flow rates, and is considered capable of obtaining specifications of CO_2 content of less than or equal to 1%.

In designing CO_2 separation using cryogenic distillation at a very high flow rate, a flow rate distribution scenario in parallel with different columns is needed to meet these needs due to limited location availability.

With the content of 71% CO_2 and 29% methane, the results of separation using two-column cryogenic distillation obtained by the case of 8000 MMSCFD flow rate obtained the number of the first column as much as 16 with a diameter of 7.4 meters and height of 17.66 meters, while the number of second columns was 4 in diameter 8 meters high and 22.38 meters.

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