Influence of mid-point temperature of heavy hydrocarbons separator to the liquefaction process for small LNG plant

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Abstract. In liquefied natural gas (LNG) process production, one of the important units is heavy hydrocarbon removal unit to prevent freezing during liquefaction. For small scale of LNG plant, this unit is usually integrated with main heat exchanger. Feed is obtained from main heat exchanger then flows to separator to separate liquid from gas. The separator operating condition is called as Midpoint condition. Selecting Midpoint conditions have impact to light hydrocarbon losses, Specific Brake Horse Power (SBHP) process, and heating value of LNG. Hence understanding of selecting this condition and its effect to light hydrocarbon losses, SBHP process, and HHV of LNG will help to design more efficient LNG plant. According to study, the lower of Mid-Point temperature will result in lower SBHP, lower of light hydrocarbon losses, and increase LNG of HHV value. Meanwhile, the higher Mid-Point pressure will result in lower SBHP, higher light hydrocarbon losses, and lower LNG of HHV value. The change of Mid-Point pressures have more impact to light hydrocarbon losses than SBHP process.

1. Introduction
Liquefied Natural Gas (LNG) is one of efficient natural gas transportation and trading methods [1]. Recently, Small Scale LNG Plant (SSLNG) is becoming very popular as a concept for liquefying gas fuel in remote area which is not connected to the gas pipe [2]. This method is much easier compared to converting the gases into other forms, such as syngas or methanol [3-6]. Some SSLNG plants obtained the gas feed from gas pipelines that have not been meet the specifications yet for direct liquefaction process because it still has a high content of heavy hydrocarbons, such as butane, pentane, hexane, and another long-chain hydrocarbons. Thus, the heavy hydrocarbons are required to be separated prior to the liquefaction process.

In SSLNG, the separation process is preferably using a simpler and cheaper separator unit (see read box in Figure 1). However, this method results in loss of light hydrocarbons such as methane and ethane that affects the LNG plant efficiency. This single-stage separation is proposed to knock-down heavy hydrocarbon at suitable operating conditions, ie. temperature and pressure, so called Midpoint separation. The discussion in this paper is trying to evaluate the influence of midpoint condition to the Specific Brake Horse Power (SBHP) of refrigeration process for LNG production and the heating value (HHV) of LNG product. In many references of LNG design, process optimization is necessary to improve the efficiency and well as the economic point of view [7,8]. Moreover, further suggestion to determine the temperature and pressure of midpoint separator could be obtained.
2. Methodology

LNG process simulation was done using the PRICO liquefaction scheme (see Figure 1) as a tool to evaluate the parameters of the study. This process was selected because it has been widely applied to SSLNG plant and has been proven to operate more than 40 years [9]. Simulations include the removal process of CO$_2$ and water from gas.

In this study, the feed gas was 50 MMSCFD. Process simulation was conducted by using Aspen Hysys while freezing point was calculated using the software GPSA Luks Solubility Solid. In some cases, process simulator could calculate and predict very well to evaluate the plant process performance, eg. [10].

2.1. Simulation Process Specification

In this study, two feed compositions have been simulated. Detail feed gas composition used in this model is shown in Table 1.

![Figure 1. Schematic process flow diagram of PRICO and single stage separator [9].](image)

| Components | Composition (%) |
|------------|-----------------|
| Feed 1     | Feed 2          |
| Nitrogen   | 0.8821          | 0.2130 |
| CO$_2$     | 0.3678          | 0.6090 |
| Methane    | 86.0445         | 88.1134 |
| Etane      | 62.5170         | 52.8430 |
| Propane    | 3.6982          | 3.3952 |
| i-C$_4$    | 0.8079          | 0.6710 |
| n-C$_4$    | 1.0085          | 0.8090 |
| i-C$_5$    | 0.3369          | 0.3070 |
| n-C$_5$    | 0.2195          | 0.1680 |
| C$_{6+}$   | 0.3831          | 0.4300 |
| H$_2$O     | 7 lbs/MMSCF     |

The composition of the refrigerant consists of nitrogen, methane, ethane, propane and isopentane[1]. The pressure loss at pre-treatment (CO$_2$ and water separation) area and main heat exchanger was assumed to be 43 psi. After the pretreatment, feed gas went to phase separator to knock down the heavy hydrocarbons or called NGL. The gas outlet from the separator then routed back into the main heat transfer equipment to be liquefied into LNG. The feed gas composition and properties
become the main criterion for determining the condition of the midpoint, as also mentioned by [11]. This gas should have a lower freezing point than the desired final temperature. With a final temperature of LNG at -260°F (-162°C) and the value for safety taken by 10°F, the highest temperature of the freezing point of the gas should be -270°F. Based on the brief simulation, the midpoint temperature has to be above -20°F to allow the freezing point of the gas is higher than -270°F.

In this study, the simulated feed gas pressures were 500 psig (low), 700 psig (medium), and 800 psig (high) with the separator temperature were varied at -30°F, -50°F, -70°F, and -90°F. Simulated pressures have been selected based on the condition of most gas natural gas pipelines in Indonesia.

2.2. Observed Parameters
In this study, the influence of midpoint condition changes has been explored and evaluated based on three observed parameters, ie. SBHP, amount of heavy hydrocarbons, and heating value.

1. SBHP (Specific Brake Horse Power)
SBHP is the energy required to produce a certain number of LNG. SBHP value indicates the efficiency of the LNG process. The lower SBHP value, the better energy efficiency of the LNG process.

2. The amount of separated heavy hydrocarbons fraction
In this study, the term separated heavy hydrocarbons refers to hydrocarbons that change into a liquid phase and separated by separator. For this study, its value is a percentage of the amount of feed gas into the natural gas liquefaction process.

3. Higher Heating Value (HHV) of LNG product
HHV is the energy content of fuel gas. HHV of the gas is obtained from HYSYS software in BTU/Scf.

3. Result and Discussion
In order to rigorously evaluate the impact to pressure and temperature changes on observed parameter, the evaluation and discussion were divided into three feed gas pressure variation, ie. 500 psig (low), 700 psig (medium), and 800 psig (high).

3.1. Feed Gas Pressure of 500 psig
At the feed gas pressure of 500 psig and the pressure loss in the pretreatment unit was 38 psi, the pressure of gas goes into the main heat exchanger were 462 psig. Furthermore with the pressure loss in the main heat transport equipment by 5 psi, then the pressure control valve in the upstream toward the midpoint was at 457 psig.

Following the result of Table 2, the mole fraction of methane in heavy hydrocarbons (NGL) at a midpoint temperature of -90°F reaches 48% greater than the midpoint temperature of -30°F. It is certainly not favorable condition since methane was expected to be converted into LNG. Meanwhile for the different feed composition (Feed 2 of Table 1), the correlation trend between midpoint temperature and percentage of separated heavy hydrocarbons was similar the same.

| Composition | T = -30°F | T = -90°F |
|-------------|-----------|-----------|
| Nitrogen    | 0.0007    | 0.0012    |
| CO₂         | 0.0000    | 0.0001    |
| Methane     | 0.2689    | 0.4806    |
| Ethane      | 0.1357    | 0.1910    |
| Propane     | 0.2449    | 0.1787    |
| i-butane    | 0.0865    | 0.0427    |
| n-butane    | 0.1221    | 0.0542    |
| i-pentane   | 0.0484    | 0.0184    |
| n-pentane   | 0.0326    | 0.0120    |
| n-hexane    | 0.0602    | 0.0211    |
A surprising result was obtained in the case of Specific Brake Horse Power (SBHP) correction. At lower midpoint temperatures, lower SBHP values were obtained that means the energy efficiency of the process is getting worse. When the midpoint temperature was decreasing, the amount of separated heavy fraction increased and lower the LNG production. The total energy supplied to the refrigerant compression is not only utilized for liquefaction process but also used to cool the heavy fraction of hydrocarbons. When most of the butane compound was required to be knocked-down from the feed gas by lowering the separation temperature, pentane and other heavier hydrocarbons were also cooled although these compounds have already been in liquid condition. This could impact the increasing value of power consumption. The second reason was due to the gas composition after phase separation. At higher midpoint temperature, the gas composition tends to be leaner means the gas has a higher concentration of nitrogen and light hydrocarbons than initial condition. This condition will significantly change the composition of refrigerant allows to match the liquefaction process. In general, leaner condition will reduce the concentration of iso-pentane in the refrigerant and increase the concentration of nitrogen and methane. As higher heat capacity compounds was reducing, the circulation of refrigerant and power increased.

Table 3. The influence of Midpoint pressure variation to SBHP, NGL fraction, and HHV.

| Midpoint Pressure (psig) | Feed 1 | Feed 2 |
|-------------------------|--------|--------|
| SBHP (kW/ton/d) | NGL (%-wt) | HHV (Btu/Scf) | SBHP (kW/ton/d) | NGL (%-wt) | HHV (Btu/Scf) |
| 367 | 17.48 | 5.328 | 1107 | 17.00 | 4.235 | 17.00 |
| 387 | 17.43 | 5.563 | 1106 | 16.91 | 4.423 | 16.91 |
| 407 | 17.30 | 5.797 | 1104 | 16.82 | 4.609 | 16.82 |
| 427 | 17.18 | 6.028 | 1103 | 16.47 | 4.793 | 16.47 |
| 447 | 16.98 | 6.259 | 1102 | 16.37 | 4.976 | 16.37 |

Table 3 shows the trend of SBHP, NGL, and heating values with variation in midpoint temperature at feed pressure of 500 psig. The SBHP trend is nearly linear with a small deviation. This means SBHP value can be assumed directly proportional with the variation of midpoint temperature. In the other hand, by comparing the curve for all pressure values we can conclude that increased value of pressure will decrease SBHP. The main reason for this fact is that the higher the midpoint pressure value, the smaller the heat was required for gas condensing process.

In contrary to the SBHP trend, lower midpoint pressures were favored for higher heavy hydrocarbon production. With increasing midpoint pressure of 5%, SBHP value has changed 0.53% lower while the heavy hydrocarbon fraction increased by 4.43%. From this discussion, increasing midpoint pressure in order to decrease SBHP value is not a good operation choice because the significant increased value of NGL which led to lower amount of LNG product.

Regarding the heating value (HHV), all variation could produce HHV values that in the normal range of LNG (1100 – 1200 Btu/Scf). Small differences were found among the values that means the different pressure did not give significant influence to the heating value of LNG.

3.2. Feed Gas Pressure of 700 psig

At the feed gas pressure of 700 psig, different situation was found to the linearly trend of SBHP and LNG products. Although the trend was similar to 600 psig condition, at current pressure, the trends have a bending point as shown in Figure 2.

Another important finding that shown by Figure 2b clearly mentioned that at critical temperature of above 70°F, the pressure changes give more influence to the SBHP rather than temperature effect. This could drive to critical operation decision of selecting the suitable pressure and temperature of the Midpoint separator. As this point could shift to other different temperatures, the decision should be made based on the feed composition and pressure. In the case of heating value (HHV), the current pressure (700 psig) also resulted almost linear trend as shown in Figure 3.
Figure 2. Influence of Midpoint temperature to (a) fraction of NGL and (b) SBHP value.

Figure 3. Influence of Midpoint temperature to HHV of LNG for (a) Feed 1 and (b) Feed 2.

3.3. Feed Gas Pressure of 800 psig
A similar situation as feed gas pressure of 700 psig was found in the case of feed gas pressure of 800 psig (Figure 4). At midpoint temperature lower than -60°F, the amount of heavy hydrocarbon (NGL) increased due to more carryover of lighter hydrocarbons. In this case, the influence of pressure gives more significant changes to the SBHP compared to feed pressure of 700 psig at temperature below -70°F. Again, this drive to the conclusion that optimization of Midpoint is necessary to be conducted based on feed composition and pressure to obtain the best process result and economics.
Figure 4. Influence of Midpoint temperature to (a) fraction of NGL; (b) SBHP; and (c) HHV of LNG.

4. Conclusion
The simulation and evaluation of Midpoint phase separator condition, ie. pressure and temperature has been conducted. From this research, regarding the effects of midpoint condition to liquefaction of natural gas using PRICO process, the conclusions can be concluded as:
1. Midpoint condition (temperature and pressure) has significant impact to SBHP, fraction of heavy hydrocarbon (NGL), and HHV of LNG. Therefore, optimization is necessary to be conducted during the process design based on feed composition and pressure.
2. Some interesting points that were obtained in this study are:
   a. Higher midpoint temperature will cause smaller SBHP/increased process efficiency, smaller percentage of heavy hydrocarbon, and higher HHV.
   b. Higher midpoint pressure will cause smaller SBHP, higher percentage of heavy hydrocarbon, and smaller HHV.
   c. Effect of midpoint pressure to SBHP is less significant than the increase of percentage of heavy hydrocarbon.
   d. Effect of midpoint pressure to SBHP is higher significant than the change of HHV.

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