Techno-economic feasibility of flare gas utilization using adsorbed natural gas

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Abstract. Adsorbed natural gas (ANG) is a natural gas storage technology, which is potential to transport natural gas in small and medium quantity. The objective of this study is to determine the techno-economic feasibility of ANG technology for flare gas to consumers around flare gas sources. The method is process simulation, economic calculation and optimization with variables being ANG selling price, flare gas price, and the percentage of capital financing by the government. The process simulation shows that the ANG product is in the range of 2.07 MMSCFD – 2.97 MMSCFD. The economic calculation results in the interest rate of return of less than 10%. With optimization, the IRR increases to more than 20%.

1. Introduction

The supply of 587 MMSCFD flare gas in Indonesia is potential to be utilized. However, due to its low flowrate and remote location, the appropriate gas transportation technology is required to utilize flare gas [1]. Compressed Natural Gas (CNG) is one of the technologies used to distribute natural gas in small to medium quantities and distances of less than 965 km. However, CNG has a deficiency in terms of safety due to relatively high operating pressure (> 200 bar). This disadvantage of CNG leads to the development of adsorbed natural gas (ANG) [2, 3]. This technology does not require liquefaction process such as liquid natural gas (LNG) or compression process such as CNG. In ANG technology, natural gas is deposited on a porous material (adsorbent) as adsorbed phase at the pressure of 3.5-4.0 MPa. The energy density of ANG at the pressure of 500 psi (~ 3.4 Mpa) is proportional to that of CNG at 2400 psi (~ 16.5Mpa) pressure [4].

ANG technology continues to grow up in line with the development of research on adsorbents for methane. It is reported in 2013 that the adsorbent of type HKUST-1 has the storage capacity of 267 V(STP)/V at 10 MPa [5]. With this advantage, ANG technology is considered to be feasible as a flare gas transportation technology that has a relatively small capacity. Therefore, the recent study is to determine the techno-economic feasibility of ANG technology for flare gas utilization to consumers around flare gas sources.

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2. Methodology
The study uses flare gases from three natural gas fields with the specification as shown in Table 1.

Table 1. Detailed specification of flare gas from three natural gas fields.

| Composition | Field X | Field Y | Field Z |
|-------------|---------|---------|---------|
| Mole fraction |         |         |         |
| C$_1$       | 0.49886 | 0.75060 | 0.80752 |
| C$_2$       | 0.03943 | 0.08900 | 0.00498 |
| C$_3$       | 0.04001 | 0.08450 | 0.00499 |
| iC$_4$      | 0.01398 | 0.01920 | 0.00498 |
| nC$_4$      | 0.02027 | 0.02250 | 0.00279 |
| iC$_5$      | 0.01098 | 0.00730 | 0.00158 |
| nC$_5$      | 0.00991 | 0.00490 | 0.00132 |
| C$_6$+      | 0.02528 | 0.00820 | 0.00267 |
| N$_2$       | 0.00227 | 0.00800 | 0.01733 |
| CO$_2$      | 0.32692 | 0.00580 | 0.15004 |
| H$_2$S      | 0.01209 | 0.00000 | 0.00180 |
| Location    | Onshore | Offshore | Offshore |
| Pressure (psig) | 77.00   | 71.00   | 75.00   |
| Temperature (°F) | 117.00  | 108.00  | 105.00  |
| Flowrate (MMSCFD) | 4.80    | 2.50    | 3.77    |

Figure 1, Figure 2 and Figure 3 show the process flow diagram of Field X, Field Y and Field Z. Field X requires compression, gas sweetening and fractionation facilities to process the flare gas. Field Y needs compression and fractionation facilities. Field Z involves compression facilities and gas sweetening facilities in the plant. The process simulation results in mass balance, energy consumption, and equipment sizes, which in turn were used to estimate the capital and operating costs. The cashflow was calculated using the following assumption: project duration = 10 years, discount factor = 10%, operating time = 330 days/year, flare gas price = 2.7 US$/MMBTU, energy price = flare gas price, ANG selling price = 7 US$/MMBTU, condensate selling price = 40 US$/BBL, LPG selling price = 300 US$/ton, and HKUST-1 price = 6.5 US$/kg.

The output of the cashflow calculation is interest rate of return (IRR), net present value (NPV), period of time (POT) and profitability index (PI). If the economic indicators indicate that the project is not feasible, then feasibility optimization is performed by: setting the ANG selling price in the range of 8-10 US$/MMBTU, based on the existing range of CNG selling price for the industrial sector in Indonesia; setting flare gas price ranging from 0.45 US$/MMBTU to 2.7 US$/MMBTU, based on the government regulation and the average selling price of flare gas in other countries; alternating the financing scheme using public private partnership where the government capital financing share is in the range of 0-100%, based on the history of government cooperation with private parties ever undertaken.

3. Results and discussion
The results of the process simulation on Field X, Field Y, and Field Z exhibits in Table 2. It can be seen in the table that the ANG production in Field Z is the highest, followed by Field X and Field Y. If
viewed from the flare gas flowrates, Field Z yields 3.77 MMSCFD flare gas, lower than 4.80 MMSCFD from Field X. The higher ANG from Field Z if compared to that from Field X is because the methane fraction in flare gas from Field Z is twice of that from Field X. The energy consumption is directly proportional to the flare gas flowrate. The higher flare gas flowrate consumes higher energy.

The capital cost, as shown in table 3 is insignificantly effected to the flare gas flowrate. This is because the flowrate in the three fields is almost the same. Capital cost is heavily influenced by infrastructure. Field Y, although its flare gas flowrate is the lowest, but its capital cost is the highest. This is because the distance between Field Y and the mainland is the farthest among the three fields that requires the capital costs for the flowline and the gathering facility.

The operating cost, as exhibited in table 4 is directly proportional to the flare gas flowrate. Field X needs the highest capital cost because its flare gas is the highest.

Figure 1. Process flow diagram of Field X.

Figure 2. Process flow diagram of Field Y.

Table 5 shows that Field Y has the best economy than the others although the flare gas flowrate is the lowest and the capital cost is the highest. This is because the flare gas from Field Y possesses the
lowest impurities (CO₂ and H₂S) resulting in the highest conversion ratio among the three fields. It appears from the table that the economics of the Field X, Field Y, and Field Z are not feasible. Therefore, it is necessary to optimize the projects of the three fields.

![Process flow diagram of Field Z.](image)

Optimization is carried out by calculating hundreds of possible scenarios. Table 6, table 7 and table 8 exhibit only five scenario results including the best scenarios. Optimization result for Field X, as seen in table 6, shows that without the Government financing Field X will be feasible with IRR being higher than 20% if the flare gas price is set at 1 US$/MMBTU and the ANG selling price is 9 US$/MMBTU, whereas with the Government financing, it will be feasible with IRR more than 20% if the government bears 70% of the capital cost and the flare gas price is set at 2 US$/MMBTU. As for Field Y, as seen table 7, with the Government financing, Field Y will be feasible with IRR greater than 20% if the government bears 40% of the capital cost, the flare gas price is 2.5 US$/MMBTU, and the ANG selling price is 10 US$/MMBTU. As to Field Z, as seen in table 8, with the Government financing, Field Z will be feasible with IRR higher than 20% if the government endures 70% of the capital cost, the flare gas price is set at 2.7 US$/MMBTU, and the ANG selling price set to 9 US$/MMBTU.

| Field       | X     | Y     | Z     |
|-------------|-------|-------|-------|
| Feed (MMSCFD) | 4.80  | 2.50  | 3.77  |
| Product     |       |       |       |
| Condensate (BBL/day) | 88.76 | 46.47 | 0.00  |
| LPG (ton/day)   | 17.89 | 18.38 | 0.00  |
| ANG (MMSCFD)    | 2.33  | 2.07  | 2.97  |
| Energy consumption (MMBTUD) |       |       |       |
| Pipeline and compression | 91.81 | 33.53 | 50.30 |
| Gas sweetening | 90.86 | 0.00  | 91.20 |
| Fractionation  | 51.72 | 29.74 | 0.00  |
| ANG filling station | 11.72 | 3.16  | 7.08  |
| **Total**     | **246.12** | **66.43** | **148.58** |
Table 3. Estimated capital cost.

| Capital cost component (US$) | X       | Y       | Z       |
|------------------------------|---------|---------|---------|
| Direct cost                  | 16,185,723 | 26,386,124 | 27,008,895 |
| Main equipment               | 12,999,064 | 19,751,993 | 20,658,988 |
| Compressor facility          | 893,750  | 536,250  | 715,000  |
| Flowline and gathering       | 285,000  | 14,915,000 | 11,275,000 |
| Gas sweetening facility      | 4,510,289 | -       | 3,854,956 |
| Fractionation facility       | 1,932,981 | 1,264,974 | -       |
| ANG filling facility         | 1,430,925 | 905,761  | 1,280,775 |
| Transportation facility      | 3,946,120 | 2,130,008 | 3,533,257 |
| Installation                 | 1,677,189 | 3,491,648 | 3,342,056 |
| Piping and instrumentation   | 1,509,470 | 3,142,483 | 3,007,850 |
| Indirect cost                | 4,279,574 | 8,330,393 | 8,095,800 |
| Engineering                  | 1,975,188 | 3,844,797 | 3,736,523 |
| Building and construction    | 1,316,792 | 2,563,198 | 2,491,015 |
| Contingency                  | 987,594  | 1,922,398 | 1,868,262 |
| **Total capital cost**       | 20,465,296 | 34,716,517 | 35,104,695 |

Table 4. Estimated operating cost.

| Operating cost component (US$/year) | X       | Y       | Z       |
|-------------------------------------|---------|---------|---------|
| Plant fixed cost                    | 799,557 | 247,654 | 534,097 |
| Labor cost                          | 137,130 | 137,130 | 137,130 |
| Plant maintenance cost              | 511,632 | 104,150 | 175,523 |
| Miscellaneous cost                  | 150,795 | 6,374  | 221,443 |
| Energy cost (variable cost)         | 239,230 | 64,573  | 144,416 |
| Pipeline and compression            | 89,244  | 32,592  | 48,892  |
| Gas sweetening facilities           | 88,320  | -      | 88,647  |
| Fractionation facilities            | 50,275  | 28,906  |         |
| ANG filling facilities              | 11,392  | 3,075  | 6,877   |
| Transportation facilities           | 1,098,587 | 592,988 | 983,648 |
| Fuel cost                           | 260,059 | 140,373 | 232,850 |
| Vehicle maintenance                 | 557,990 | 301,188 | 499,611 |
| Driver cost                         | 258,958 | 139,779 | 231,865 |
| License cost                        | 21,580  | 11,648  | 19,322  |
| **Total operating cost**            | 2,137,375 | 905,214 | 1,662,161 |

Table 5. Economic simulation result.

| Result                        | X            | Y       | Z       |
|-------------------------------|--------------|---------|---------|
| Total cashflow, US$           | 3,239,789    | 8,791,045 | (10,172,147) |
| POT (PBP), year               | 10.64        | 9.73    | 0.00    |
| IRR                           | 1.77%        | 3.75%   | -4.37%  |
| NPV, US$                      | (9,111,223)  | (9,093,169) | (20,920,597) |
| PI (BCR)                      | 0.63         | 0.74    | 0.43    |
Table 6. Field X optimization result.

| Scenario | Government capital share | ANG price (US$/MMBtu) | Flare gas price (US$/MMBtu) | Private cashflow | Government cashflow |
|----------|--------------------------|------------------------|----------------------------|------------------|---------------------|
|          |                          |                        |                            | IRR              | NPV (MUS$)         | IRR      | NPV (MUS$) |
| 7        | 0%                       | 10                     | 2.7                        | 10.81%           | 957                | -        | 40,327    |
| 22       | 0%                       | 7                      | 1.5                        | 10.42%           | 445                | -        | 24,419    |
| 33       | 0%                       | 9                      | 1                          | 20.37%           | 11,139             | -        | 23,946    |
| 344      | 70%                      | 7                      | 2.7                        | 12.44%           | 1,511              | 30.61%   | 21,002    |
| 347      | 70%                      | 8.5                    | 2.7                        | 20.30%           | 6,546              | 33.62%   | 23,843    |
| 358      | 70%                      | 7                      | 2                          | 22.45%           | 7,086              | 24.08%   | 15,037    |

Table 7. Field Y optimization result.

| Scenario | Government capital share | ANG price (US$/MMBtu) | Flare gas price (US$/MMBtu) | Private cashflow | Government cashflow |
|----------|--------------------------|------------------------|----------------------------|------------------|---------------------|
|          |                          |                        |                            | IRR              | NPV (MUS$)         | IRR      | NPV (MUS$) |
| 14       | 0%                       | 10                     | 2.5                        | 10.46%           | 699                | #NUM!    | 24,454    |
| 197      | 40%                      | 7                      | 2.7                        | 11.20%           | 1,204              | 14.92%   | 7,058     |
| 210      | 40%                      | 10                     | 2.5                        | 20.40%           | 10,996             | 20.12%   | 11,229    |

Table 8. Field Z optimization result.

| Scenario | Government capital share | ANG price (US$/MMBtu) | Flare gas price (US$/MMBtu) | Private cashflow | Government cashflow |
|----------|--------------------------|------------------------|----------------------------|------------------|---------------------|
|          |                          |                        |                            | IRR              | NPV (MUS$)         | IRR      | NPV (MUS$) |
| 34       | 0%                       | 9.5                    | 1                          | 11.36%           | 2,113              | #!       | 18,830    |
| 345      | 70%                      | 7.5                    | 2.7                        | 11.64%           | 1,169              | 7.57%    | 3,006     |
| 348      | 70%                      | 9                      | 2.7                        | 20.35%           | 7,660              | 9.71%    | 5,645     |

4. Conclusion
The ANG technology would be optimal for fields having flare gas with high methane content and low impurities. The economics of flare gas utilization using ANG technology will be feasible if the financing pattern being the cooperation between privates and the Government where the part of Government cost capital is more than 40%.

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6. References
[1] KESDM 2016 Handbook Economic & Energy Statistic of Indonesia Jakarta
[2] Zheng Q R, Feng Y L, Zhu Z W and Wang X H 2016 Appl. Therm. Eng. 98 778
[3] Vasiliev L L, Kanonchik L E, Mishkinis D A and Rabetsky M I 2000 Int. J. Therm. Sci. 39 1047
[4] Nie Z, Lin Y and Jin X 2016 Front. Mech. Eng. 11(3) 1
[5] Peng Y, Krungleviciute V, Eryazici I, Hupp J T, Farha O K, Yildirim T 2013 J. Am. Chem. Soc. 135 11887