REVIEW ON ECONOMICAL EFFICIENCY OF LNG COLD ENERGY USE IN SOUTH KOREA

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ABSTRACT

About 10 years ago, Korea Gas Corporation (KOGAS) carried out a feasibility study on businesses using Liquefied Natural Gas (LNG) for cold power generation, air separation, cryogenic crushing, frozen food storage, and carbonic acid. Recently, an air liquefaction plant started operations near Pyungtaek Receiving Terminal (R/T) and a cryogenic crushing plant is now partially operating near Tongyoung R/T. However, although the business of air separation has already been industrialized, the problem of increasing the amount of gas sales remains. It has been revealed that there is more increased demand in the gas-phase market than the liquid-phase market, and that there exists a different demand pattern between the air separation plant and the LNG plant. Accordingly, the final object of this study is to establish a comprehensive business plan on the use of LNG cold energy in which all situations in South Korea are taken into consideration. Here, this report deals mainly with the economical efficiency of LNG cold energy use in South Korea based on several previously published reports.

First, we performed an exergy analysis on the process of LNG receiving terminals and obtained the amounts of exergy available in the present process. From the results, the cold power generation plant was investigated using the Osaka process and the Linde process among four known processes. Economical efficiency was then analyzed by the revenue requirement method and the internal rate of return method. The total cost consisted of return on equity, return on debt, book depreciation, fuel costs, operating & maintenance costs, insurance fees, and so forth. Although their payback periods were thought to be 11.7 years for the Osaka process and 4.2 years for the Linde process according to a KOPEC report in 1989, in actuality, their payback periods were 18.6 years and 17.5 years, respectively, from the results of this study.

The air separation plant using 50 T/H of LNG was examined with the rated capacity to produce oxygen, nitrogen, and argon. Its payback period was found to be 5 years from an HDE report in 1996. However, this study revealed that the actual payback period was 14.6 years due to the fact that the liquid-phase market share, which once stood at 80 percent, decreased to 20 percent, and that the plant barely operates during summer due to the Boil-Off Gas (BOG) treatment of receiving terminals.

The cryogenic crushing plant is no longer operating under cryogenic conditions but normal temperature. The Ministry of Commerce, Industry and Energy in a report in 2000 stated the payback period to be 3.1 years. But the prospect is not clear due to small market share in South Korea. It may depend on the development of the overseas market which is a larger market than that in Korea. The payback periods of the frozen food storage and carbon acid plants were 7.1 years and 6.6 years, respectively, from the HDE report.

Although this work is ongoing, KOGAS has reached certain conclusions, such as the amounts and priority of capital investment. However, some unclear points on the cost and technologies of LNG cold facilities still remain. In the near future, KOGAS will investigate these matters in detail in order to update economical efficiency and establish a new plan on the industrialization of LNG cold facilities.
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REVIEW ON ECONOMICAL EFFICIENCY OF LNG COLD ENERGY USE IN SOUTH KOREA

1. PREAMBLE

KOGAS has been carrying out a feasibility study on the use of wasted LNG cold energy in receiving terminals. Although KOGAS investigated all possible areas of LNG cold energy use about 10 years ago, the results are not reasonable due to changes in market share and the amount of LNG cold energy now available in receiving terminals. In particular, application of the air separation plant to the LNG terminal of KOGAS is very difficult because Boil-Off Gas (BOG) has currently increased and market share of liquid-phase gas has decreased.

Consequently, this work is to review the present status of LNG cold energy in the receiving terminals of KOGAS and the economical efficiency of LNG cold energy use in South Korea. First of all, the total amounts of LNG cold energy available were investigated through an exergy analysis and applied to targeted systems using LNG cold energy. Cold power generation and air separation were completed in detail, with the others still ongoing. In the near future, KOGAS will also complete them in detail and establish a new plan on the industrialization of LNG cold energy facilities.

2. THEORETICAL APPROACHES

2.1 Energy and Exergy Analysis

Energy and exergy analysis(1) is used to evaluate the amounts of LNG cold energy available in the receiving terminals and the objected LNG cold energy facilities. The method of exergy analysis is particularly suited for furthering the goal of more efficient energy resource use, for it enables the locations, types, and true magnitudes of waste and loss to be determined. The energy rate balance for energy analysis is as follows:

\[
\frac{dE_{cv}}{dt} = \dot{Q}_c - \dot{W}_{cv} + \sum_i \dot{m}_i \left( h_i + \frac{V_i^2}{2} + g z_i \right) - \sum_e \dot{m}_e \left( h_e + \frac{V_e^2}{2} + g z_e \right)
\]

where the first term is zero at steady state, the second is the heat transfer rate, the third is the work rate, and the fourth and fifth are the rates of energy transfer in and out across the boundary. By definition, exergy is the maximum theoretical work obtainable as the environment and some closed system interact to equilibrium. The exergy rate balance can be derived using a conservation law and applied to the thermal system. The result is
\[
\frac{dA_{ex}}{dt} = \sum_j \left(1 - \frac{T_0}{T_j}\right)Q_j - \left(W_{cv} - p_0 \frac{dV_{ex}}{dt}\right) + \sum_i \dot{m}_a n - \sum_e \dot{m}_a e - I_{cv}
\]

where the first term is zero at steady state, the second is exergy transfer accompanying heat transfer, the third is exergy transfer accompanying work, the third and the fourth are exergy transfer accompanying mass flow, and the last term is irreversibility as exergy destruction.

### 2.2 Economical Analysis

Evaluation on the economical efficiency of LNG cold facilities uses three methods: IRR(Internal Rate of Return) method, NPV(Net Present Value) method, and PPM(Payback Period Method). IRR uses the following equation

\[
\sum_i^n \left( \frac{CI_i}{(1 + r)^i} \right) = \sum_i^n \left( \frac{CO_i}{(1 + r)^i} \right)
\]

where CI and CO mean cash in and cash out, \(n\) is the period of evaluation, and \(r\) is IRR. NPV becomes

\[
\sum_j^n \left( \frac{CI_j}{(1 + K^-)^j} \right) = \sum_j^n \left( \frac{CO_j}{(1 + K^-)^j} \right)
\]

where \(K^-\) is the discount rate which meets the end of cash in and cash out. PPM is taken as

\[
\sum_t^n \left( \frac{CI_t}{(1 + K)^t} \right) = \sum_t^n \left( \frac{CO_t}{(1 + K)^t} \right)
\]

where \(K\) means a discount rate. IRR and NPV consider the time value of currency, but PPM does not. The accuracy of economical analysis largely depends on the correct presumption of cash flow made by some capital investment plan. The cash flow on each LNG cold facility of this work was updated as costs were recalculated according to the producer price index of previously published reports. Finally, the economical efficiency was given by IRR, NPV, and PPM on the basis of fixed charge, changed charge, thermal performance, and working rate on each facility.
3. AVAILABLE LNG COLD ENERGY

LNG cold energy available in receiving terminal depends on the relation of NG supply and BOG from LNG storage tanks and pipe lines. The amount of cold energy also differs depending on the time of the year. After LNG goes through a BOG recondenser, cold energy and exergy are decreased to 2.7% and 3.6% in winter, and to 9.5% and 11.8% in summer. Finally, the surviving energy and exergy are 12.4% and 63.1% in winter, and 13.1% and 58.5% in summer, after the LNG goes through vaporizers. From the results, the mean amounts of energy and exergy available in the receiving terminal become 185.3 kW and 75.1 kW per LNG ton. This corresponds to 81.0% and 31.5% of total energy and exergy, respectively. In fact, the amount of energy cannot be properly applied to LNG cold facilities because it is relatively made by reference to the amount of energy at water of 273.15 K. The amount of 75.1 kW per LNG ton was the maximum available from LNG cold energy in the receiving terminals of KOGAS.

A difficult problem in the use of LNG cold energy is the rising temperature of LNG required to recondense BOG, which mainly occurs from storage tanks and pipe lines. In particular, it has a large effect on air separation plants in the summer season due to high demand in winter and low demand in summer as shown in Figure 1. In fact, it is very difficult for the Incheon and Tongyoung receiving terminals to apply the air separation plant since NG supply is lower than the required minimum supply of NG for an air separation plant from April through October. As well, a Seoul cold air products company near Pyungtaek R/T finds it difficult to effectively operate the plant due to the large deviation of NG supply over time in the summer season.

In the view of economical efficiency, a correct evaluation of commercialization of facilities using LNG cold energy is closely associated with the available LNG cold energy and the NG supply pattern in each receiving terminal, as well as market share.

![Figure 1: Supply patterns of NG in each receiving terminal in 2005](image)
4. ECONOMICAL EFFICIENCY

4.1 Cold Power Generation Plant

The economical efficiency of a cold power generation plant was analyzed on the basis of a Korea Power Engineering Company (KOPEC) report\textsuperscript{(2)} published in 1989. Among four well-known processes—the Hitachi, Linde, Osaka and Toshiba—only two were used in this investigation, the Osaka process and the Linde process.

Figure 2 shows the results of energy and exergy analysis on the Osaka process and the Linde process. The Osaka process can obtain 17.6 kW per LNG ton, and the Linde process 29.5 kW per LNG ton. The energetic and exergetic efficiencies are 12.2% and 18.5% in the Osaka process, and 20.3% and 30.8% in the Linde process. Although we can find the large difference between the Osaka process and the Linde process, we cannot yet entirely confirm whether the Linde process is actually better than the Osaka process because the Linde process has not yet been commercialized. As well, it is known that the Linde company has developed a new Linde process.

From the available LNG cold energy in the receiving terminal of KOGAS\textsuperscript{(3)}, if the Osaka process is applied to KOGAS, the electrical power obtainable may be 14.8 kW per LNG ton, which comes under 84% of the electrical power from the Osaka process. Finally, the cold energy and exergy available for cold power generation in KOGAS turned out to be 93.9% and 84.0% of the required cold energy and exergy by the existing process. The results show that the profits from cold power generation are less. Accordingly, when the existing process is applied to KOGAS’s terminals, it is required that the economical effects be clarified through economical analysis.

When the cold power generation of the Osaka process generates 28.8 GWh with LNG of 200 T/H, it requires an investment of US $23.9 million and operating expenses of US $0.6 million, with profits of US $1.3 million obtained. From the KOPEC report, the IRRs of the Osaka and Linde processes were 8.57% and 24.41%, respectively, and the payback periods were 11.7 years and 4.2 years. But economical efficiency was found to be much lower in this study than in the KOPEC report.

![Figure 2: Energy and exergy analysis on (A) Osaka process and (B) Linde process](image-url)
The IRRs revealed 2.64% for the Osaka process and 2.70% for the Linde process. The payback periods were identified as 18.6 years and 17.5 years, respectively.

4.2 Cold Air Separation Plant

An air separation plant operated by a Seoul cold air products company was examined on energetic and exergetic efficiencies. Figure 3 shows LNG flow, which is linked with Pyungtaek R/T and Seoul cold air products by a Seoul Cold Air Products (SCAP) facility which is referred to as a special facility using LNG cold energy. This study investigated the SCAP facility only in terms of the thermal performance of LNG. The energy and exergy of LNG used in the SCAP facility were observed to be 10.6% and 56.0% of total energy and exergy, respectively. The exergetic efficiency turned out to be 67.8%, but the energetic efficiency was unclear due to the small quantity of use of total LNG cold energy.

Economical efficiency was examined with a cold air separation plant using 50 T/H of LNG, which can produce 9,400 Nm$^3$/H of oxygen, 9,400 Nm$^3$/H of nitrogen, and 387 Nm$^3$/H of argon under rated conditions. From the results of a Hyundai Engineering (HDE) report published in 1996, the initial investment and operating expenses were US $70.1 and US $9.5 million, respectively. The profits obtainable through the operation were predicted to be about US $22.4 million; while IRR, NPV, and the payback period were recorded at 21.9%, US $67.8 million, and 5.0 years, respectively. Here the costs were recalculated by the producer price index. When changes of market share and the available LNG energy in the receiving terminals of KOGAS were considered, the results are largely changed.

Figure 3: Seoul cold air products connected with LNG line of KOGAS by SCAP
From the results of this study, IRR, NPV, and the payback period were found to be 11.0%, US $0.6 million, and 14.6 years, respectively. However, KOGAS believes that cold air separation actually gives lower profits than the results because its drawbacks include effective operation that is dependent both on time and season and gas demand.

### 4.3 Cryogenic Crushing Plant

A cryogenic crushing plant which can produce rubber powder amounting to 10,000 tons per year has been in operation since the end of 2005 under normal temperature crushing (not cryogenic) near Tongyoung R/T. It can crush wasted tired of 1.1 T/H with LNG of 3.7 T/H. In fact, the plant may increase facilities investment this year after guaranteeing domestic or foreign market shares. KOGAS is now in the process of investigating the details of cryogenic crushing.

From the results of a report\(^{(5)}\) published by the Ministry of Commerce, Industry and Energy in 2000, investment, operating cost, and profits were reported as US $13.6, $1.3, and $2.5 million, respectively; and IRR, NPV, and the payback period were 27.0%, US $13.9 million, and 3.1 years, respectively. However, the payback period was actually stated to be 8.7 years according to a proposal by KOGAS and Kolon Construction Company in 2003. Finally, a Cryotec company, which is operating a cryogenic plant, reported red profits of about US $9.8 thousand in 2006. Some unclear points about the prospect of the cryogenic crushing still remain. In the near future, KOGAS will conduct a detailed investigation on the cryogenic crushing business.

### 4.4 Frozen Food Storage and Carbonic Acid

Frozen food storage and carbonic acid using LNG cold energy are not currently present in South Korea. With the economical efficiency from the HDE report, frozen food storage which uses LNG of 4.7 T/H requires capital investment and operating cost of US $13.6 and $1.3 million, respectively, with obtainable profits of US $2.5 million. IRR, NPV, and the payback period were reported to be 13.8%, US $3.5 million, and 7.1 years, respectively. The carbonic acid plant which produces carbonic acid of 16.7 T/H with LNG of 163.5 T/H, recorded investment, operating cost, and profits of US $16.5, $4.7, and $3.2 million, respectively. IRR, NPV, and the payback period were observed to be 15.0%, US $5.5 million, and 6.6 years, respectively.

KOGAS has not formed any concrete conclusions on the technical, financial, and marketing data of the plants since its investigation is ongoing. In the near future, their existing economical efficiency will be updated.

As an added area of LNG cold energy, KOGAS has a plan to examine a complex cooling system in the new town of Songdo near Incheon R/T in Incheon City. According to some of the literature, the effect of LNG cold energy on air conditioning was thought to be high cost and low profits. To assist the
Korean government to enforce its policy of regenerating wasted energy, KOGAS will conduct an analysis on the complex cooling system linked with other LNG cold facilities.

5. CONCLUDING REMARKS

In this research, KOGAS surveyed some promising businesses on their use of LNG cold energy. Table 1 shows the comprehensive results of this study. If KOGAS undergoes the business on power generation, IRR and PPM are 2.6% and 18.6 years, respectively, in the case of the Osaka process; and 2.7% and 17.5 years, respectively, in the Linde process. The business of air separation reveals IRR of 11.0% and a payback period of 14.6 years. KOGAS is still conducting research on the three remaining businesses, and as such, cannot yet validate the results of the previous literatures. The cold crushing business showed IRR of 12.4% and a payback period of 8.7 years; the frozen food storage business was found to have IRR of 13.8% and a payback period of 7.1 years; and the carbonic acid business recorded IRR of 15.0% and a payback period of 6.6 years.

Consequently, three businesses--cold crushing, frozen food storage, and carbonic acid--seem to have the most prospects in South Korea. However, if they are considered in light of the present market share situation and in terms of the amount of LNG cold energy in the receiving terminals of KOGAS, they may show very low economical efficiencies. Although this work is ongoing, KOGAS has reached certain conclusions on the amount and the priority of capital investment. Some unclear points about the costs and technologies of LNG cold facilities still remain, however. In near future, KOGAS will investigate these issues in detail in order to update economical efficiency and establish a new plan on the industrialization of LNG cold facilities.

Table 1: Results of the economical efficiency on LNG cold facilities

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6. REFERENCES

2. KOPEC (1989), Feasibility Study on Cold Power Generation.
4. KOGAS & HDE (1996), Feasibility Study and Basic Plan on LNG Cold Energy.

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