ENERGY SAVING POTENTIAL FOR NATURAL GAS HYDRATE TRANSPORTATION

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Introduction

Gas hydrates are inclusion compounds in which cage-like structures formed by hydrogen-bonded water molecules can hold a variety of guest molecules such as methane, CO_2. Applications of gas hydrates have drawn attentions in the field of energy and environment. Gudmundson et al.[1] proposed a new concept of transportation of natural gas in the form of gas hydrates. Major components of natural gases, methane and ethane, could form gas hydrates. The guest molecules are densely included in the hydrates; the volume per one mole is 1/170 of that of gas at the atmospheric pressure. This is favorable for the storage and transportation of gases in the form of hydrates. In addition, gas hydrates are stable under the conditions of higher temperatures than liquefaction temperature of the natural gas components. This would lead an advantage of the transportation process in the form of gas hydrates over the conventional liquefied natural gas (LNG) transportation, because milder conditions during the transportation are required for the gas hydrates, which will reduce the cost of heat insulation to prevent the dissociation or evaporation.

The reduction of the energy consumption is of primary importance for the implementation of the NGH transport process. Several studies have been conducted on the evaluation of energy consumption by NGH transportation, and the results demonstrated that NGH transportation is advantageous both from energy consumption and cost. For more reduction of the energy consumption for the transport, several options can be considered. One option is a utilization of additives on the hydrate formation to moderate the hydrate equilibrium conditions, which could result in the reduction in the energy consumption for the hydrate formation as well as that during the transportation in a carrier ship of NGH. In this study, the effect of the additives on the energy consumption of NGH transport scenario was examined quantitatively, and energy-saving potential was estimated.

Natural Gas Hydrate Transportation Process

Overview. Natural gas produced from a gas well will be pressurized and cooled to a hydrate formation condition, and converted to natural gas hydrate (NGH) in a stirred tank type reactor. Then, the NGH will be loaded in a hydrate carrier ship, and transported to a consumption site located 6000 km distance from the gas well. In the consumption site, the NGH will be dissociated by heating with seawater flow, and natural gas will be recovered for use.

Assumptions and procedure for energy consumption estimation. The following assumptions were made for the estimation of the energy consumption for the NGH transport scenario.

1. Natural gas production rate

Production rate of natural gas from a natural gas field is assumed at 1.13×10^7 m^3/day, which corresponds to a typical natural gas well. Since the heat generation by the combustion of methane is 890 kJ/mol, the total energy potential in the natural gas produced is 4.49×10^{12} J/day. The condition of the produced natural gas is at the atmospheric pressure (0.1 MPa), and at the temperature of 288.15 K. The composition of the natural gas is assumed as pure methane, and no separation or purification process is necessary before hydrate formation.

2. Pre-treatment of natural gas for hydrate production

The feed gas is pressurized by a compressor from 0.1 MPa to a set pressure for the hydrate formation by an adiabatic compression process of ideal gas with the compression efficiency at 0.8. The cooling of the compressed gas is carried out by 2 step; 1st step: cooling to 323.15 K by using seawater flow at 298.15 K; 2nd step: brine refrigeration with the coefficient of performance, COP = 4.

3. Hydrate formation process

Hydrate production is conducted in a stirring vessel type reactor at a given condition of hydrate formation. The pressure and temperature of the hydrate formation conditions are set as operational variables for the energy consumption estimations. The base temperature is assumed at 275.15 K, and the base pressure is assumed at 6.0 MPa.

The feed water is supplied by a pump, and cooled from 298.15 K to the hydrate formation temperature by a brine refrigeration system with COP = 4. The hydration number of the methane hydrate is assumed at 5.75 corresponding fully occupied cages in type I hydrate. Hydrate formation rate is taken from experimental data conducted in a laboratory-scale experimental set-up (volume = 1.2×10^{-3} m^3, reaction rate = 3.72×10^{-4} mol/s at 25 rps stirring rate). The power consumption for the stirring process in the model reactor is given by the Nagata's equation, and results on laboratory-scale experiments can be scaled-up under the assumption that the energy consumption for stirring per unit volume of the feed mixture is constant in the scaled-up reactor. The energy consumption for the removal of the heat of formation is considered for the pumping energy of the brine, and cooling for recovery of the brine temperature.

4. Refrigeration of methane hydrate

After removal of the remained water from the natural gas hydrates, the hydrate will be refrigerated to a lower temperature in which the hydrate is stable under the atmospheric pressure. The remained water at the surface of methane hydrate is assumed at 12.0 wt. %. The energy for refrigeration is calculated for a refrigeration process with COP = 4, and specific heat and latent heat of ice are taken from the literatures.

5. Transportation of natural gas hydrate by a NGH carrier ship

The hydrate is transported in an adiabatic tank in the transportation ship. The energy consumption for the transportation is 2.8×10^{-3} kg-Fuel/t/mile (http://nippon.zaidan.info), which corresponds to 87.5 J/kg/m. The transportation distance is assumed at 6000 km.

6. Dissociation of natural gas hydrate -recovery of natural gas

The dissociation of the hydrate is carried out by heating the hydrate by a seawater flow of which the temperature is 298.15 K.

Energy Consumption Results

Energy consumption for the base case was shown in Table 1. Since the combustion energy in the natural gas is 5.195×10^3 MW, about 14 % of total energy will be consumed in the NGH transportation scenario. More than half of the energy consumption

could be attributed to the transportation process in a NGH carrier ship, and next major energy consumption sector is pretreatment of the natural gas for hydrate formation including pressurization and cooling. In the following sections, the influences of the operational parameters on the energy consumption were investigated.

Table 1. Breakdown of Energy Consumption for The Transport Scenario of NGH (base case)

Energy consumption sector	Energy consumption [MW]	Percentage [%]
Pretreatment	190.56	25.31
Hydrate formation	130.77	17.34
Refrigeration	14.18	1.88
Transportation	410.35	54.49
Dissociation	7.16	0.95
Total	753.0	100.00

1. *Effect of the hydrate formation rate*

Hydrate formation rate is a function of a variety of factors such as agitation rate, temperature, and pressure. Some additives such as surfactants can dramatically increase the hydrate formation rate. Figure 1 shows the influence of the hydrate formation rate on the energy consumption of the hydrate formation process.

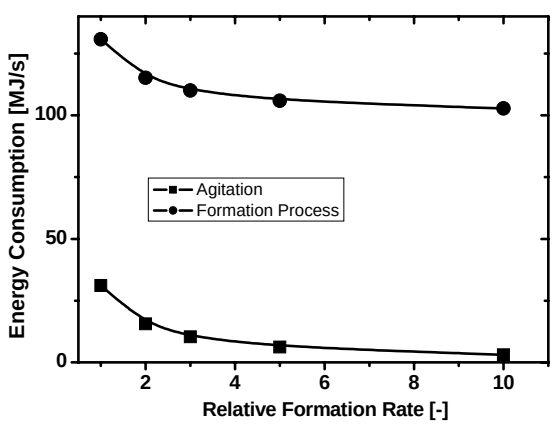

Figure 1 Effect of the hydrate formation rate on the energy consumption in the hydrate formation process

Energy consumption of the agitation for the hydrate formation gradually decreased with an increase in the hydrate formation rate. For the case with 10 times larger hydrate formation rate, the energy consumption for the agitation could be reduced at about 1/10 resulting in about 3.7 % of the total energy consumption.

2. *Effect of the temperature for the hydrate transport*

NGH is transported in a carrier ship at the temperature under which the hydrate is stable under the atmospheric condition. This temperature could be changed by using hydrate formation helper compounds. Also, some additives used for the promotion of the hydrate formation rates could be used as stabilizer of the hydrate during the transportation. Considering the above effect, effect of the hydrate transport temperature on the energy consumption is calculated and the results are shown in Figure 2. In the present cases, the energy consumption for the refrigeration is shown. Although energy consumption for the refrigeration decreased linearly with the increase in the transport temperature, but the effect of the reduction on the total energy consumption is less than 1 % at the highest temperature studied, i.e., 273.15 K.

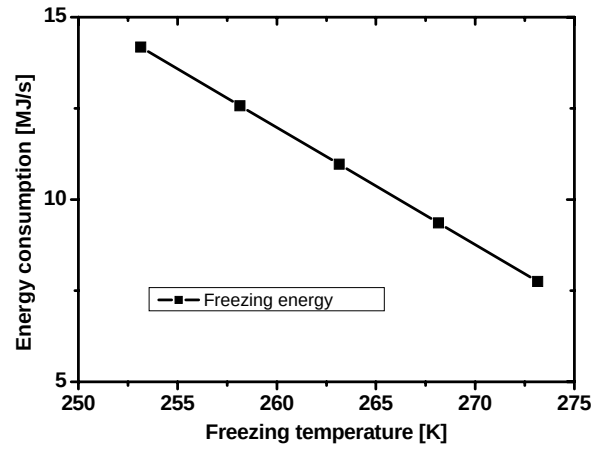

Figure 2 Effect of the hydrate transport temperature on the energy consumption for the refrigeration

3. *Effect of the hydrate formation conditions*

Hydrate formation conditions could affect the pre-treatment process of natural gas stream before the hydrate formation process. Figure 3 shows the effect of the hydrate formation pressure on the energy consumption for the pre-treatment (pressurization and cooling) process. The energy for the pre-treatment process increased with an increase in the hydrate formation pressure, and the energy saving potential for the case of 3.0 MPa is about 7.7 % compared with the base case at 6.0 MPa.

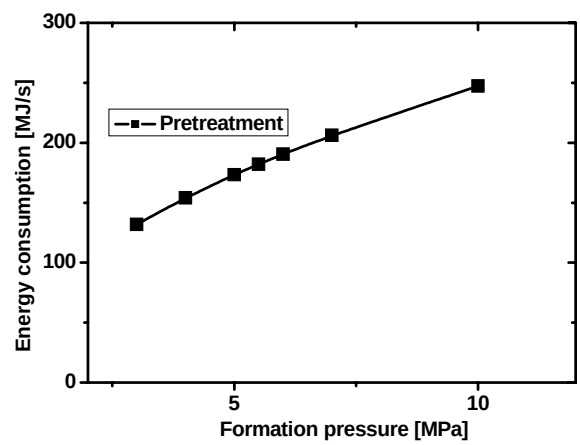

Figure 3 Effect of the hydrate formation pressure on the energy consumption for the pre-treatment process of natural gas stream before hydrate formation

References

[1] Gudmundson, J. S. et al., *Proc. 2nd International Conference on Natural Gas Hydrates* (**1996**).