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LONG DISTANCE TRANSPORT OF NATURAL GAS HYDRATE TO JAPAN

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ABSTRACT

Commissioned by J-Power (Electric Power Development Co., Ltd) in Japan, Aker Kvaerner Engineering & Technology has carried out a study to directly compare production, transportation and regasification of Natural Gas Hydrates (NGH) with the same-size chain of Liquefied Natural Gas (LNG). The paper addresses a novel concept for using NGH for large scale, long distance gas transportation, as a competitor to LNG technology. The base case NGH chain is for 3 million tonne/year (MMTPA) LNG equivalent to 400 MMSCFD of gas. The transport distance is 6000 kilometres, corresponding to a shipment from South East Asia to Japan. The NGH chain consists of three main elements; hydrate production terminal, hydrate carriers and regasification terminal. The paper addresses and discusses the maturity of these elements and possible improvements of the concept. Three alternative cases (chain sizes) are also discussed. These are LNG equivalent capacities of 2.0, 1.0 and 0.5 MMTPA. Some recent (post study) activities from J-Power in Japan have also been included in the paper.

INTRODUCTION AND BACKGROUND

Natural Gas Hydrates have been shown to be “meta-stable” at atmospheric pressure and at moderate sub-zero temperatures. Hydrates have been produced in laboratories and stored at “home freezer” temperatures for long periods without appreciable loss of gas, and it is this phenomenon which forms the basis for the concept of transporting gas as solid hydrates.

An attribute of hydrates is that the substance is meta-stable at moderate conditions. This, together with the potential high gas content of hydrate, forms the basis for the idea that hydrates can be used for gas transport. Hydrate technology has been evaluated by Aker Kvaerner and the Norwegian University of Science and Technology (NTNU) since early 1990's as an alternative way to capture and transport natural gas. Cost estimates have indicated that capital cost of hydrate technology may for some developments be considerable lower than e.g. LNG (liquefied natural gas) and pipeline transport. See e.g. Gudmundsson et al. [1], [2] for summaries of the hydrate technology and different possible applications.

The basic idea behind the proposed NGH technology is founded on the two following aspects:

- Work done by Professor J. S. Gudmundsson et al. at NTNU (Norwegian University of Science and Technology), demonstrating that natural gas in hydrate form is stable at ambient pressure and temperatures around -15°C.
- Natural gas hydrates can be readily formed at ambient or near ambient temperatures at moderate pressures as shown in Figure 1 below, simply by allowing water and natural gas to contact in a stirred reactor.

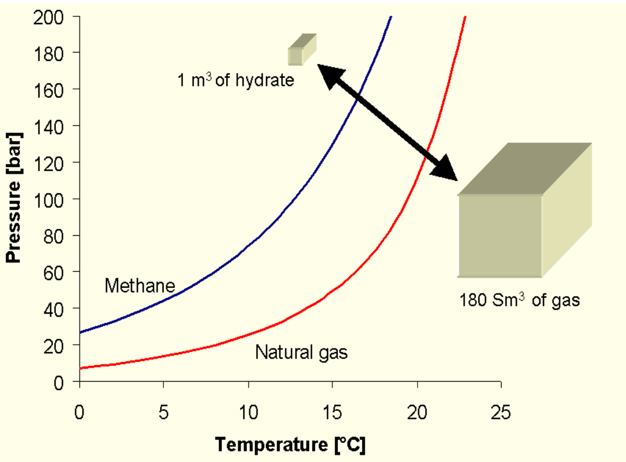

Figure 1: Equilibrium lines for methane hydrate and gas mixture hydrate, indicating ideal volume reduction of gas when forming hydrate.

Liquefied Natural Gas (LNG) is a state of the art method for both storage and transport of large gas volumes, as is pipelines for transport. Pipeline transport costs for a given volume is virtually a function of transport distance. LNG transport chains are characterised by a high investment in the LNG production plant itself, whilst the cost of LNG vessels will be a function of distance.

NGH transport chains will exhibit the same characteristics as LNG, but at a lower cost due to much reduced size and amount of cryogenic equipment and piping. The process described herein is based on a high degree of existing technology and equipment, but adapted for NGH process requirements.

HYDRATE TRANSPORT CHAIN

The hydrate transportation chain is split into three major components, covering the entire gas value chain. These NGH elements are:

- Production facilities including inlet gas treatment
- Transportation
- Regasification facilities

The base case production rate was 3 MMTPA of LNG equivalent. This is approximately 400 MMSCFD or 11.3 million Sm3/d of natural gas being converted to hydrate at the production plant. The production facility will have four 25% (100 MMSCFD) production trains. This is large-scale for NGH technology, which is expected to have a greater advantage compared to LNG for small-to-medium-scale field developments.

The turbine drivers in particular determine the 100 MMSCFD train size. Typical turbine sizes required are in the range of 25 to 30 MW and there are commercially available turbines in both industrial machine segment and aero derivative segment. The cost estimate is based on aero derivative turbines.

NGH regasification directly in the carrier has been introduced. Fresh water is circulated for hydrate melting. The added water must finally be pumped from the carrier and returned to the water heating system.

To obtain a grid pressure of 70 bar there are four compression trains (100 MMSCFD each) with a total compression duty of approximately 55MW. Compressor after-coolers and seawater/freshwater exchangers are supplying the hydrate melting energy.

HYDRATE PRODUCTION

The gas arrive the NGH production plant by pipeline at 70 bara and 20°C. The gas composition used is as given in Table 1 below.

Table 1: Natural gas composition used in the study.

Component	Mole %
C_1	93.9
C_2	1.2
C_3	0.35
C_4+	0.35
CO2	3.0
N_2	1.2
H_2S	0.0030

Pre-treatment facilities are required for handling of the H_2S content. The CO_2 content does not require special attention as the partial pressure in the process is below limits normally set for corrosion control. The CO_2 will form hydrates and will thus remain in the gas throughout the chain. In principle, the gas treatment required at the production site is limited because gas grid specifications are easier and more cost effective to achieve at the receiving end of the chain.

A simplified flow diagram of the NGH production process is shown in Figure 2. The production process starts with hydrate formation in a reactor where natural gas and cold water are mixed. A large amount of energy, representing the hydrate heat of formation, is released during the process and absorbed by large amounts of direct cooling water. Since the hydrate production facilities are located in a tropical climate zone, in the present study the cooling water of 36 C will have to be refrigerated. The refrigeration is a mixed refrigerant loop with a compressor duty of 23 MW per production train. The water is cooled from +8°C to +2°C representing a water flow rate and duty of approximately 7900 tonnes/h and 95 MW respectively. Refrigerant compressors are turbine driven.

Reactor conditions chosen are 65 to 70 bara pressure and between 2 to 8°C temperature, which means that the conditions are well within the hydrate stability area. Actual optimal/operational conditions will vary with factors such as natural gas composition, chemicals present, reactor control, reactor design, etc.

A conventional Continuous Stirred Tank Reactor (CSTR) has been chosen for the design of the NGH production plant. A CSTR will be favourable for the important parameters in the NGH reaction; that is, mass transfer and heat removal. Agitation (stirring) will ensure the best mass transfer area for the NGH production.

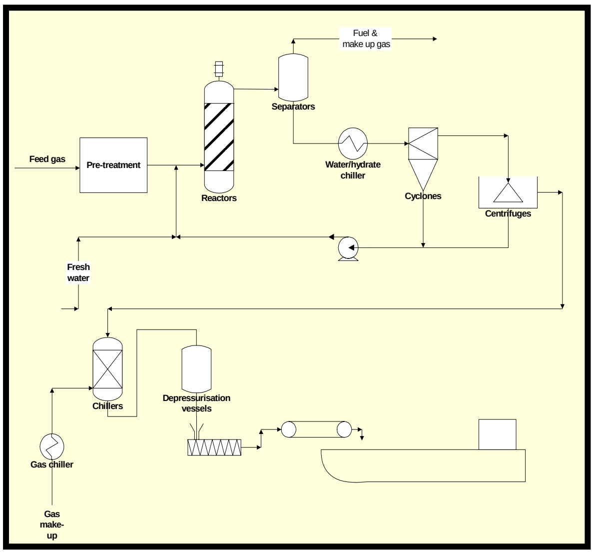

Figure 2: Simplified flow diagram of the NGH production process.

The large amount of cooling water required determines the size of the reactors. In the present design there are three reactors in series per train with water cooling between the 1st and the 2nd stage reactor.

The hydrate is dried in two sets of separation equipment producing high G-forces. First, the bulk water is separated in hydrocyclones leaving a 50/50 mixture of water and hydrates for the next separation stage. Then, this mixture is routed to banks of centrifuges for final dehydration. Other technologies may also be considered in future designs.

The dry, stable hydrate is led to chillers where the temperature is dropped to -15°C. The pressure is subsequently released in depressurisation tanks and the hydrate is in its meta-stable condition at ambient pressure.

Insulated belt conveyor transports the hydrate from the depressurisation tanks to the ship.

No hydrate storage has been provided at the production plant and hydrate is directly transferred to the carrier.

Particle size and form may affect agglomeration, flowability, solids handling, heat transfer and therefore hydrate melting rate, etc. It can be influenced by factors such as the driving force (distance from equilibrium line) in the and impurities (or injected chemicals) present. The quantity of natural gas in the hydrate volume has been assumed to be 150 Sm^3/m^3 pure hydrate. The distance from the equilibrium line may influence the degree of filling (representing the number of cages filled with gas molecules), size of hydrate particles formed, hydrate composition, etc. Details have not been studied in the present work.

NGH meta-stability is assumed not to be influenced by separation, drying, freezing or depressurisation, which are all parts of the production process. No loss of gas from hydrates during the production process has, therefore, been accounted for. During an actual process a certain loss would be expected, such a loss could be routed to fuel gas system

ENERGY CONSUMPTION

The curves in Figure 3 below show a comparison of specific energy consumption for a NGH plant and LNG plant. Five major points should be noted:

- The seawater temperature greatly affects the energy consumption of both the NGH and LNG plant. The effect on the energy consumption of the NGH plant is higher than the effect on the LNG plant because the temperature difference in the cooling cycle is less for NGH than for LNG.
- The seawater lift pumps energy consumption is included in the NGH production estimate whilst it is not in the LNG production estimate.
- The reference LNG plant is a world class design with respect to energy consumption using Mixed Fluid Refrigerant Cascade Process. A lot of effort has been put into optimising these types of plants with respect to energy consumption.
- In tropical areas it is recommended to use seawater intake at certain depth, to ensure cold water supply.
- A potential exists for reducing the specific power consumption of the NGH production plant.

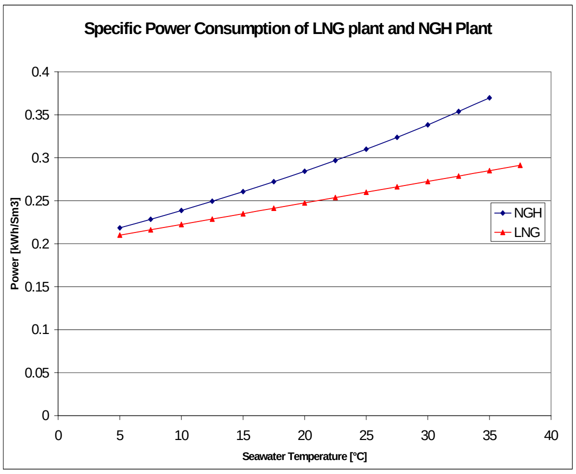

Figure 3: specific power consumption of LNG and NGH plants plotted against cooling water temperature.

SHIPPING

The selected NGH carriers are insulated crude ships fitted with equipment for solids handling.

The carriers have an overall length of 357 m, a breadth of 60 m and a design draft of 36.1m. Their loading capacity is 322 000 tonnes and maximum cargo volume is 460 000 m^3. The design service speed is 15.0 knots in transit and 15.8 knots in ballast.

The fabrication time and cost of a NGH carrier are much less than for a LNG carrier. The fabrication of a NGH carrier does not require a specialised yard, familiar with LNG tank design. The NGH carrier cost inclusive large pumping equipment and ducting for the water, is USD 100 million each, or USD 704 million for the 7 carriers needed for the 6000 km run.

REGASIFICATION

NGH regasification is carried out directly in the carrier implying compression from atmospheric to pipeline pressure. There are four compression trains (100 MMSCFD each) and total compression duty is approximately 55 MW. A gas turbine system, type LM 2500, has been chosen.

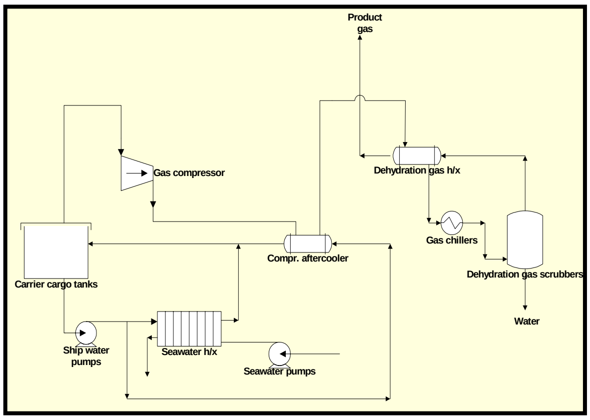

Figure 4: Regasification of NGH.

Fresh water is used as heating medium for the regasification. The fresh water is heated by a combination of utilising the same water for cooling water to the compressor after-coolers, exhaust gas waste heat recovery system and exchanging with seawater. The fresh water return pumps from the carriers can either be submersible pumps or similar to conventional crude offloading pumps. The latter has been assumed and included in the carrier cost estimate.

The hot fresh water is added directly to the hydrate melting process at the regasification plant and water contained in the hydrate is released. Approximately 90 000 tonnes is transferred (intermittent), via NGH carrier as ballast water, to the production plant, and reused.

POST STUDY EVALUATIONS

Some post study activities have been carried out by J-Power in Japan. An alternative NGH gas chain has been established.

A spray NGH reactor has been evaluated and compared to the Continuous Stirred Tank Reactor (CSTR). The spray reactor gives reduction in the capital cost for the NGH production plant.

Modifications have been made for the NGH carriers. Several smaller carriers have been selected. Refrigerating and conveying systems have been included in the carriers. As a result of these modifications, the capital cost for NGH carriers has been increased for the J-Power alternative.

The regasification plant has been simplified by using waste heat from a gas power plant. These modifications give some reduction in the cost of the plant.

The cost comparison between the study and the alternative J-Power design is included in Table 2 below.

COST COMPARISON

The total capital cost for NGH production plant, carriers and regasification was estimated to 1838 million UDS. The total operating cost is estimated to 110 million USD/Y, excluding the cost of consumed gas.

The total capital cost of a similar capacity LNG chain, including production, carriers and regasification was estimated to 2090 million USD.

CONCLUDING REMARKS

A total NGH transportation chain has been established for a 3 MMTPA gas capacity. The chain includes a NGH production facility, 7 carriers and regas facility. The transport distance is 6000 km. The total capital cost for the NGH chain is 12% lower than for a similar LNG chain.

The cost estimate for the LNG chain is more firm than for the NGH chain. The LNG technology is more mature than for NGH. It is thereby a greater potential for improvements and future cost reduction in the NGH chain.

The NGH chain comprises less cryogenic equipment and piping, and the NGH carriers are much simpler (and take less time) to fabricate compared to LNG carriers.

The pre-treatment of the gas to a NGH production plant is simplified. Dehydration and CO2 removal will not be required normally. This reduced treatment is a great advantage for offshore NGH applications.

The selected 6000 km transport distance is favouring the LNG carriers.

The selected seawater temperature of 36 ^{o}C is favouring the LNG production chain. The hydrate production process is highly dependant on seawater for heat removal.

The 3 MMTPA LNG production facility comprises one single train and the similar capacity NGH facility comprises four production train. A reduction in production capacity will thereby favour the cost of NGH versus LNG.

J-Power has established an alternative design. The costs for the NGH production plant and regasification facility have been reduced. An alternative NGH carrier concept has been selected resulting in an increased cost.

The NGH technology is novel and non-mature. However, the NGH technology has an interesting potential for monetizing gas fields of less than 3 MMTPA gas production rate and transport distance to user of less than 6000 km. Low cooling water is favourable for NGH.

REFERENCES

1. Gudmundsson, J.S., Andersson, V. and Levik O.I.: "Gas Storage and Transport using Hydrates", *Offshore Mediterranean Conference*, Ravenna, March 19-21, 1997

2. Gudmundsson, J.S., Mork, M. and Graff, O.F.: "Hydrate Non-Pipeline Technology", *4th International Conference on Gas Hydrates*, Tokyo, May 19-23, 2002.

Table 2 The Capital Cost of NGH Chain

[MMUSD]

Capacity (LNG equivalent)		3.0 MMTPY	2.0 MMTPY	1.0 MMTPY	0.5 MMTPY
Production	AKET	992	743	456	284
	J-Power *1	788	567	325	-
Carriers	AKET *2	628	538	359	269
	J-Power *3	1 080	720	360	-
Regasification	AKET *2	218	174	116	83
	J-Power *3	152	110	63	-
Total	AKET	1 838	1 455	931	636
	J-Power	2 020	1 397	748	-

*1 spray-type reactor
*2 regasification in carriers
*3 land-based regasification