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Simulation and economic evaluation of natural gas hydrates [NGH] as an alternative to liquefied natural gas [LNG]

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Abstract

Despite the fact that relatively little is known about the ultimate resource potential of natural gas hydrates, it is certain that gas hydrates are a vast storehouse of natural gas and significant technical challenges need to be met before this enormous resource can be considered an economically producible reserve. In this theoretical study, a simulation scheme was suggested to produce NGH in an industrial scale using pure water as a carrier and seawater as a cooling source. Parametric study was carried out and rigorous design calculations for different operating parameters were investigated. Further more and economical evaluation was done taken data of locally produced LNG as a comparison. Production rates, storage and transportation from production region to consumer's ends were investigated. Results obtained suggested that NGH with little consideration can be a good alternative for fuel gas carrier.

Keywords: Natural gas hydrates; Liquefied natural gas; Simulation; Economic evaluation; MATALB

1. Introduction

Gas hydrates occur in sedimentary deposits under conditions of pressure and temperature present in permafrost regions and beneath the sea in outer continental margins. The combined information from Arctic gas hydrate studies shows that, in permafrost regions, gas hydrates may exist at subsurface depths ranging from about 130 to 2000 m. The presence of gas hydrates in offshore continental margins has been inferred mainly from anomalous seismic reflectors known as bottom-simulating reflectors, which have been mapped at depths below the sea floor ranging from about 100 to 1100 m. Current estimates of the amount of gas in the world's marine and permafrost gas hydrate accumulations are in rough accord at about 20,000 trillion cubic meters [1,2].

2. Natural gas hydrates (NGH) simulation

Fig. 1 shows the suggested process for the production of natural gas hydrates (NGH). The detailed description of the process is explained by Javanmardi et al. [3]. The material balance equations and the simulation parameters equations are explained below.

Using the free water content of the water–natural gas hydrate slurry fed to the dryer, i.e. 12 wt.%, the parameter F, can be obtained in the following manner:

$$r - \frac{1}{F} = 0.12 \cdot \left(\frac{\text{NG}}{W} + r\right)$$

$$F = \frac{1}{0.88 \cdot r - 0.12 \cdot [M_{\text{w,NG}}/M_{\text{w,water}}]} \quad (1)$$

where r is the feed of water/feed of natural gas; NG the flow rate of natural gas in m^3/s; W the flow rate of water in m^3/s; $M_{\text{w,NG}}$ the molecular weight of natural gas; $M_{\text{w,water}}$ is the molecular weight of water So. The water–natural gas hydrate slurry leaving the separator is $r - 1/F$ moles water + 1 mole hydrate/mole of natural gas fed to the process. The hydrate

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Nomenclature

CP	heat capacity (J/(g °C))
F	hydrate free water content, dimensionless
$H_{hydrateD}$	the enthalpy of hydrate former at T_{dryer} and the feed pressure (J/g)
$H_{hydrateR}$	the enthalpy of hydrate former at $T_{reactor}$ and the reactor pressure (J/g)
H_{ice}	ice enthalpy (J/g)
H_{water}	water enthalpy (J/g)
$M_{w,NG}$	the molecular weight of natural gas
$M_{w,water}$	the molecular weight of water So
NG	flow rate of natural gas in (m^3/s)
Q	total heat duty (J)
r	feed of water/feed of natural gas ratio
$T_{reactor}$	reactor temperature (°C)
$T_{feed\ water}$	temperature of feed water (°C)
T_{HX}	heat exchanger temperature (°C)
T_{dryer}	dryer temperature (°C)
W	flow rate of water (m^3/s)

formation process can be represented by the following equation:

$$(1\ \text{mole})\ H_2O + (F\ \text{moles})\ \text{hydrate former} \rightarrow (F\ \text{mole})\ \text{hydrate crystal} \quad (2)$$

The heat of formation for one mole of hydrate crystal can be evaluated by the following equation:

$$\Delta H = H_{\text{hydrate crystal}} - \text{hydrate former} - \frac{1}{F}\ \text{hydrate water} \quad (3)$$

where H is the enthalpies in J/g.

This reaction is an exothermic and the heat of formation can be evaluated using available modes.

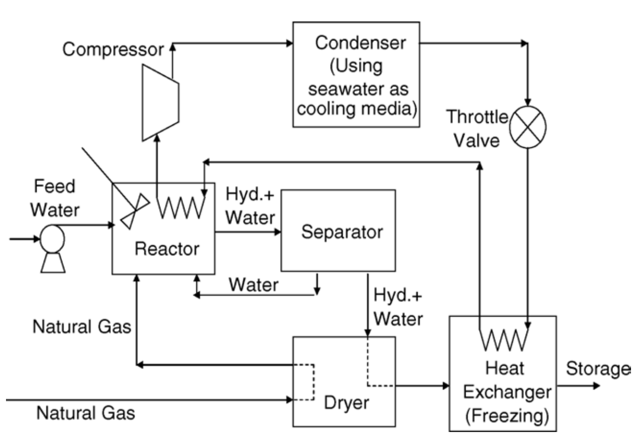

Fig. 1. Proposed NGH production setup.

For each mole of natural gas fed to the reactor, the first law of thermodynamics is written:

$$\text{Reactor duty} = -H_{hydrateD} + H_{hydrateR} + r \cdot CP_{water} \cdot [T_{reactor} - T_{feed\ water}] \quad (4)$$

where $H_{hydrateD}$ is the enthalpy of hydrate former at T_{dryer} and the feed pressure; $H_{hydrateR}$ the enthalpy of hydrate former at $T_{reactor}$ and the reactor pressure; $T_{reactor}$ is reactor temperature; $T_{feed\ water}$ is temperature of feed water.

The two phase flow stream of the hydrate slurry and water after passing through the dryer is fed to the heat exchanger. As mentioned above, the output temperature of this stream is equal to the storage temperature of hydrate.

The cooling duty of the heat exchanger can be estimated using following equation. In this equation, the hydrate heat capacity reported by Rueff et al. [4] has been used.

$$\text{Heat exchanger duty} = \left(r - \frac{1}{F}\right) \cdot (CP_{water} \cdot [T_{HX} - 273.15]) + CP_{water} \cdot (T_{HX} - 273.15) + \left(r - \frac{1}{F}\right) \cdot (H_{ice} - H_{water}) + CP_{hydrates} \cdot (T_{HX} - T_{dryer}). \quad (5)$$

where T_{HX} is the heat exchanger temperature; T_{dryer} the dryer temperature; H_{ice} the ice enthalpy; H_{water} is water enthalpy.

The total duty of the refrigeration cycle is consisted as the reactor and heat exchanger duties:

$$\text{Total heat duty} = \text{reactor duty} + \text{heat exchanger duty} = Q \quad (6)$$

To find the volume on natural gas hydrates in storage, the following equation was used.

$$Q = m \cdot CP_{hydrates} \cdot T_{LMTD} \quad (7)$$

The above equations were used as function in a subprogram using MATLAB for solution.

3. Results and discussion

The MATLAB function program was used and the following parameters were varied to study the sensitivity of the simulation program:

1. reactor temperature,
2. cooler temperature and
3. hydrate ratio.

Table 1 shows the optimum operation condition and reactor parameters for the NGH simulators.

The above structural is using the model analysis of the hydrate.

Table 1
Optimum operation conditions for NGH simulators

Reactor temperature (°C)	45
Cooling water (°C)	04
Hydrate ratio	9
F, hydrate free water content	0.128
Reactor heat duty (W)	06.448E+8
Heat exchanger heat duty (W)	02.704E+5
Total heat duty (W)	6.0450E+8
CP of hydrate (J/(mol K))	229.722
Product hydrate flow rate (m^3/day)	8938.00

3.1. Effect of reactor temperature

The reactor temperature was varied and the other parameters were kept constant. The simulation program was run and the amount of hydrates formed was calculated. Fig. 2 showed that the large hydrate is formed at reactor temperature of 45 °C. Very low hydrate production rate was shown at 25 °C; this behavior cannot be yet explained.

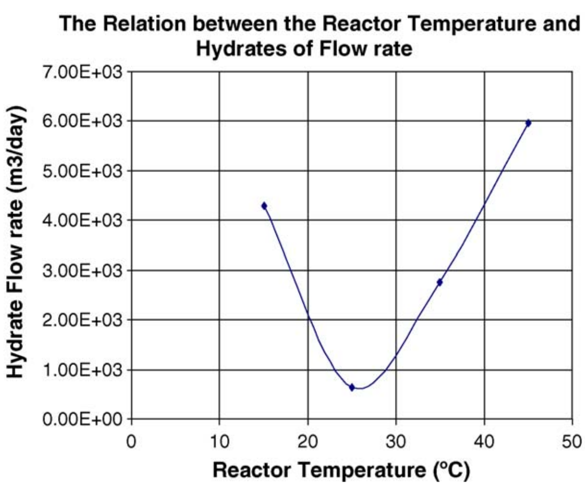

Fig. 2. Effect of reactor temperature in the NGH production.

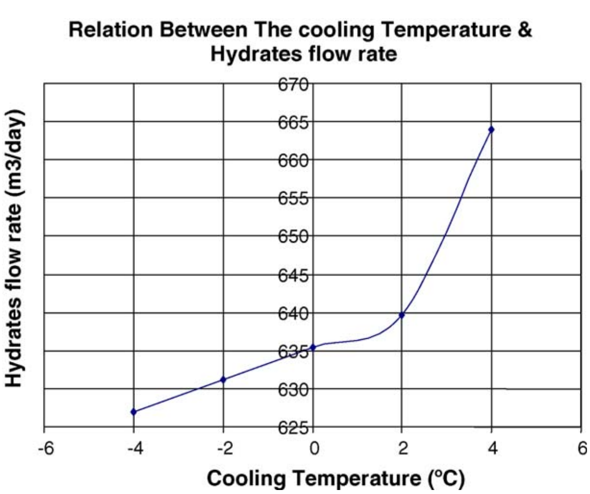

Fig. 3. Effect of cooling water temperature.

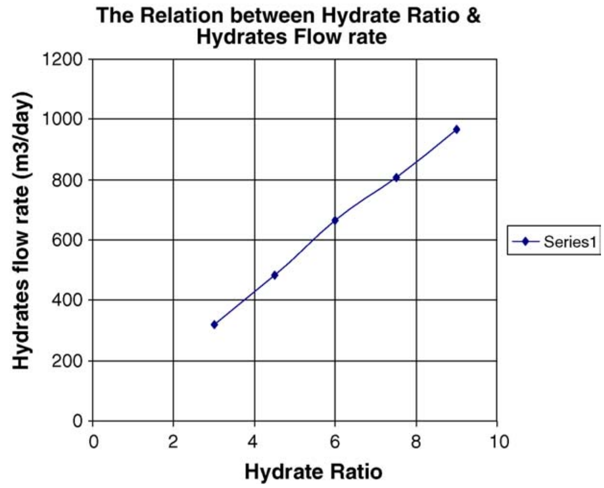

Fig. 4. Effect of hydrate ratio.

3.2. Effect of cooling temperature

The sea water cooling temperature was varied and the amount of the NGH was calculated. The temperature selected were the range at which hydrate water will be frozen. The maximum NGH formed was at 4 °C.

3.3. Effect of water hydrate ratio

The effect of hydrate ratio was varied and the amount of NHG formed was calculated. The increase in the amount of water was followed by an increase of the amount of NGH. This behavior is quite obvious since the increase in the water volume will increase the amount of natural gas hydrate (Figs. 3 and 4).

4. Conclusions

Technology for the use of hydrates for the storage of natural gas is being developed. The use of natural gas hydrates to transfer natural gas on offshore, especially when the gas is stranded, located away from pipelines and markets, is a candidate for an early application of hydrate technology. The cost of hydrate technology will in the end determine whether it will be used instead of the competing techniques. Therefore, it is important to carry out cost studies for comparison purposes. We can see from the results that the best conditions for producing NGH are in 45 °C for the reactor temperature, 4 °C for cooling temperature and the hydrate ratio is 9. In those cases, the flow rate of NGH = 8938.00 m^3/day.

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