Conceptual Study for a “Gas Hydrate Carrier Ship”

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Abstract: - The concept of transporting natural gas to distant overseas locations in the form of gas hydrates is discussed and a concept for ships for the carriage of unitized gas hydrate bulk cargo is introduced. The gas hydrate-carrying unitized barges also provide the opportunity for the storage of natural gas at coastal stations. The properties of gas hydrates dictate the installation of certain equipment for the transformation of natural gas into gas hydrate and vice-versa and for the maintenance of gas hydrate in that form, which in turn require certain onboard equipment and shore-based facilities. The concept for two specific ship concepts for the transportation of gas hydrates are introduced.

Key-Words: gas hydrate, bulk transportation and storage, CNG carrier ship, Panamax size ship, Suezmax size ship

1 Introduction

Gas hydrates or clathrates are polyhedral shaped crystalline structures which light hydrocarbons form with water under high pressures and at temperatures near the freezing point of water. Found in the nature at certain locations in seabed sediments over 300 m of depth and under arctic permafrost layer, they are regarded as one of the future sources of energy. They are also well-known to natural gas engineers as a potential threat for clogging the pipelines should the conditions for their formation exists. Detailed information on the molecular structures of gas hydrates can be found in reference [1].

Present day practice for the bulk transportation of natural gas to long distances are the surface or undersea pipelines and also ships designed for carrying compressed natural gas (CNG) and liquefied natural gas (LNG). CNG carriers have to carry natural gas at high pressures typically in the 120-240 bar range, the lower figure corresponding to a gas rich in propane and ethane and the higher figure rich in methane. Those high pressure values require heavy equipment and extra safety features, while LNG carriers carry it at near-atmospheric pressures at about -162°C, which require special tanks and extra equipment built from cryogenic material and heavy insulation about the tanks. Present day LNG carriers have typical carrying capacities of 120 000-140 000 m³, while ships with capacities up to 260 000 m³ have been built. One cubic meter of liquid cargo typically releases 600 m³ of commercial natural gas[1].

Another feature of LNG carriage is the “boiloff”, or part of the cargo let to evaporate to keep the low
temperature. Typical values of boiloff are in 0.1-0.15 percent range. The amount of boiloff can therefore amount to a 2-3% of the cargo for a typical laden voyage of about three weeks. While this boiloff natural gas is often used in ship propulsion plant on the laden leg of the voyage, it can also be re-liquefied and returned to the cargo tanks. The quest for the minimization of boiloff loss dictate high ship speeds at about 20 knots, which is an economic drawback for LNG ships, in addition to the efforts required for liquefying natural gas at the port of lading, loading it to the ship tanks and unloading it at the port of unlading.

The amount of gas which shall not be used immediately can be stored in special locations, especially in geological formations such as aquifers, depleted gas or oil reservoirs and salt caverns. The equipment related to storage also requires an extra investment.

The problems involved in carrying natural gas and high amounts of investment required have led researchers to search other ways, such as chemical conversion of natural gas into methanol or ammonia, or transporting it in the form of gas hydrate [2],[3],[4]. Although gas hydrate ship concept is not new, the only concept so far proposed is based on the existing LNG carrier vessels, with a 300 m ship length and 155 000 m³ carrying capacity [5]. The purpose of this paper is to propose an alternative concept, involving ships and shore facilities. Since the conversion of natural gas into gas hydrate and vice-versa are time-consuming processes, the idea of transporting gas hydrates in unitized tanks installed on barges similar to the lighter aboard ship (LASH) units has been developed. Since the market for natural gas is between two ports, similar to that of crude oil trade, the port of lading and the port of unlading, the entire unitized cargo barges of the vessel can be given at a time and empty gas hydrate barges can be loaded on the vessel at the port of unlading. This concept also offers the possibility of storing the gas hydrate in the same barges for transportation with the price of keeping it at about 0–1 °C.

2 Physical properties of gas hydrates

Gas hydrates are polyhedral shaped crystalline structures formed by light hydrocarbon (methane, ethane and propane) molecules and water under high pressures and low temperatures. Liquid-gas phase diagrams are shown in figure 1 for methane, ethane and propane gas hydrates [6]. Therefore, the formation of gas hydrate crystalline structures is possible by the contact of cooled water and natural gas under high pressure, and the dissociation by the release of pressure and/or by heating.

Fig. 1. Phase diagrams of simple methane, ethane and propane hydrates [7]

For the purpose of this paper, a conservative assumption that the natural gas to be transported is pure methane, since the main component of commercial natural gases are methane, to 85% and over [7].

The density of methane hydrate is 912 kg/m³. One cubic meter of gas hydrate releases 0.80 m³ of water and 164 m³ of natural gas when dissociated [8]. Although this figure is inferior to that of the LNG (1 m³ of LNG releases about 600 m³ of methane) and is of the same order as that of CNG, the pressures involved are more easy to handle compared to that of CNG and the temperatures involved can be maintained with proper insulation and external cooling.

3 The concept for gas hydrate for transportation and storage of natural gas

The conditions for keeping gas hydrates rich in methane for prolonged times is obvious from figure 1: Pressures at about 3 MPa (30 bars) and temperatures at about 0-2°C (273-275 K) are necessary both for the formation and transportation of gas hydrate. An alternative condition for the storage of gas hydrates will be keeping the gas hydrate at about –73 °C (200 K) and at atmospheric pressure. This latter case requires extra insulation,
near-cyrogenic equipment and means for refrigeration. Therefore, keeping the gas hydrate at about 0 °C and 3 MPa is preferred. Although more advantageous when compared to LNG and CNG modes from easily maintainable temperature and pressure points of view, gas hydrates still require external refrigeration to about 0-2 °C and tanks to endure 3 MPa pressure for prolonged storage and transportation. Economic evaluation of natural gas hydrate transportation has been made by several authors and logistic aspects have been studied [2],[3],[4], [9]. All have agreed about the viability of the concept.

A process has been proposed for the transformation of natural gas into gas hydrate [10]. This process is based on a stirring-vessel type reactor under about 6 MPa pressure and 2 °C temperature. Zhang et al has reported that the process of gas hydrate formation is greatly enhanced by the inclusion of certain additives in the water [11]. The product will then be stripped off from excess water, where a slurry of gas hydrate that can be pumped into the tanks of the barges under pressure. This process is energy consuming and require facilities which occupy a significant space and weight and hence should be installed in the port of lading. Daimaru et al have predicted that 25% of the energy for the transportation of natural gas by in gas hydrate form is for pre-treatment, 17% for hydrate formation, 1.9 % for refrigeration while underway and 55.5% for transportation[10] for a typical voyage of 6000 nautical miles. Since the transformation of natural gas into gas hydrate and vice-versa is time consuming, a modular system of transportation is proposed. In order to minimize the heat loss per volume of natural gas hydrate, a spherical tank configuration was selected. The spherical tanks are placed into rectangular barges, which can be stowed on the submersible deck of a ship. When fitted on the place, the barges will be integrated with the ship’s body, clamped in place to maintain structural integrity together with the ship. The openings between the side platings of the ship and barges have to be sealed with adhesive strips to maintain hydrodynamic smoothness. Powering and other services required on the barges during the voyage are to be maintained by the ship through connections fitted.

The size of the barges should be as large as possible to minimize heat lost at ambient temperatures above the temperature of the cargo, roughly 0 - 2 °C. Currently applied Panamax size was conceived for the baseline unitized barge (32 m in beam and length, containing a spherical gas hydrate tank of about 28 m in diameter). The envisaged loaded draught of the barge shall be about 12.5 m. When filled to 96 % level, each tank shall carry about 10 000 m³ of gas hydrate, which will release $1.64 \times 10^3$ m³ of natural gas.

Each barge shall contain fittings for filling of gas hydrate and extraction of natural gas, pumps and piping for stripping off the remaining water inside the tank, refrigeration unit for keeping the cargo temperature within desired limits, fittings for external heating for the extraction of natural gas from the gas hydrate and insulation around the tanks. A low capacity refrigeration system circulating brine at about -5 to -2 °C within coils inside the tanks which can be powered from the ship or from the shore was conceived. Extraction of natural gas can be made by pumping seawater of about 18-25 °C to through the same coils used for refrigeration. The remaining water can either be pumped overboard or recycled for other use. Compared to CNG tanks of about the same size, steel tank weight shall be lowered by a factor of 4 to 8, due to the reduction of tank pressure. The tanks can be manufactured from steel, from composite material or from steel with externally reinforced by wound yarns.

![Connection for loading and gas extraction](image1)
![Pressure tank for Gas Hydrate](image2)
![Insulation](image3)
![Refrigeration and heating coils](image4)
![Stripping pump for water](image5)

**Fig. 2 Unitized Gas hydrate transportation and storage barge, internal and external fittings and systems**

The same barges used for transportation can also be used as an alternative storage location for natural gas.
3.1 Two ship types proposed

Baseline “Panamax size” Gas Hydrate Carrier (GHC) ship (fig 3, 4): As an illustration to the baseline vessel for the carriage of the barges proposed above, a Panamax size vessel was conceived. The vessel shall have a beam of 32 m, with capacity to carry four of the unitized barges described above. With an expected service speed at about 16 knots, the vessel shall have an overall length of 200 m, a draft of 14 m and a displacement of 73000 metric tons. With the tanks loaded to 96% capacity, the vessel shall carry 40 000 m$^3$ of gas hydrate, or about 6.6 million m$^3$ of natural gas. This is equal to about 10900 m$^3$ of LNG cargo.

Large “Suezmax size” GHC ship (fig 5, 6): An alternative design is the equivalent of ULCC type tankers: A vessel to carry two rows of unitized barges described above, with a total of 16 barges. The envisaged sizes of the vessel are 320 m overall length, 64 m beam, 15 m draught. This vessel shall be able to transit through the Suez canal, and therefore can be named as “Suezmax GHC Ship”. The total cargo capacity shall be 160 000 m$^3$ of gas hydrate, equivalent to about 43700 m$^3$ of LNG cargo. Due to its high beam to draught ratio, it will be necessary to propel this ship with a twin screw system.

Fig. 3. Baseline Gas Hydrate Carrier Ship (“Panamax” size), with unitized barges containing gas hydrate tanks

Fig. 4. GHC ship (“Panamax” size), midship section, with unitized gas hydrate barge unit installed
4 Conclusion

As shown by several authors, the transportation of natural gas to overseas locations in the form of gas hydrates is a viable concept. Therefore, the authors have developed ideas about the transportation of gas hydrates by sea. Since the formation and dissolution of gas hydrates is a time-consuming process, the quest for reducing the time spent at port has led the authors to propose a unitized cargo concept peculiar to that concept. The idea behind the “LASH” concept of the past decades was revived, this time for the carriage of gas hydrate tanks. The system proposed can also be used for the storage of natural gas. Ideas for the conceptual design for unitized cargo natural gas hydrate carrier ships were introduced.

References:


Fig. 5. Gas hydrate carrier ship (“Suezmax” size)

Fig. 6. Gas hydrate carrier ship (“Suezmax” size), midship section, with unitized gas hydrate barge units installed


[8] web.deu.edu.tr/seislab/

