ydrates ships were estimated lower in apital costs than the LNG ships. The ne identified "pipe" represents the apital cost of a typical pipeline ransporting natural gas estimated for 20 nches pipeline on the sea bottom. The igure shows that for distances greater han about 1000 km the capital cost of a pipeline is higher than for hydrates. In the case of LNG the cross- over distance is about 1800 km. For reference the capital cost of pipelines on land is about twice the cost of the same diameter pipelines offshore [3].

Natural gas hydrates formation and decomposition

Natural gas hydrates stored adiabatically at atmospheric pressure about the freezing point of water are expected to decompose slowly into gas and water. For decomposition to occur thermal energy is required. The thermal energy can be extracted from neighboring hydrate particles. For transporting of natural gas in hydrates form challanges are:

- Formation of hydrates.
- Separation of hydrate crystals from slurry.
- Optimum storage and transportation conditions.
- Regasification of hydrates.
- Economical review of above items.

A block diagram of production of hydrates is shown in Fig. 3 and that of regasification of hydrates is shown in Fig. 4.

RIPI hydrate setup

In the first step to study kinetics of hydrates formation, we designed a laboratory setup. The RIPI hydrate setup is designed to operate at up to 400 bar pressure and at constant temperature in the range of 0-20°C. Fig 5 gives a schematic diagram of the RIPI rig. The basic units of the setup are a blind bubble reactor (working up to 400 bar), a glass bubble reactor (working up to 60 bar), a separator, a heat exchanger and a diaphragm pump. The 600 Cm^3 blind reactor is a bubble column reactor where mixing is achieved with circulation of liquid using a pump.

Hydrate forming gas is injected into the reactor through a sparger located at the bottom of the reactor. We use a check valve to prevent back flow of reactor liquid into gas lines. Also we use a plexi-glass reactor for observing liquid flow inside the reactor.

The unconverted gas is separated from the slurry in a 1000 Cm^3 separator. Circulation of hydrate slurry in the loop is achieved with a diaphragm pump, with a maximum flow rate of $15Cm^3$/ min. A simple shell and tube heat exchanger is used to remove the heat generated during hydrate formation. Several instruments are used to measure and regulate the process parameters. These instruments include Hise pressure gage, thermocouples and mass flow meter to measure the gas injection and vent rates.

Experimental results

The aims of this project are providing data for the design of natural gas hydrate processes for using in the oil and gas industry. Hydrates crystal are formed when pressure and tempereture are within the hydrate region. Beacause of one-inch diameter pipes, no plugging has been observed. Pure methane and ethane and mixture of them and a typical natural gas have been used to hydrates formation. Fig. 6 and Fig. 7 are selected results of our experiments.

Acknowledgement

This paper reports part of a work supported by RIPI (Research Institute for Petroleum Industry). The authors wish to thank Mr. Shakoori for his many useful technical helps.

References

1- Nagelvoort, R. K. and P. J. A. Tijm, 1994, "Cost reduction in LNG export facilities", Natural gas processing [13]4, World Petroleum Conference, Stavanger, pp. 9.

2- Gudmundsson J. S., Borrehaug A., 1996, "Frozen hydrate for transport of natural gas", 2nd International conf. on natural gas hydrates, June 2-6, Toulouse, France.

3- Gudmundsson J. S., V. Andersson, O.L.Levik and M. Parlaktuna, "Hydrate concept for capturing associated gas", SPE 50598.

1- Semnan University- Eng. Dept.

2- University of Tehran - Fanni Faculty - Chem. Eng. Dept.

3- NIOC-Ripi

4- Ibid

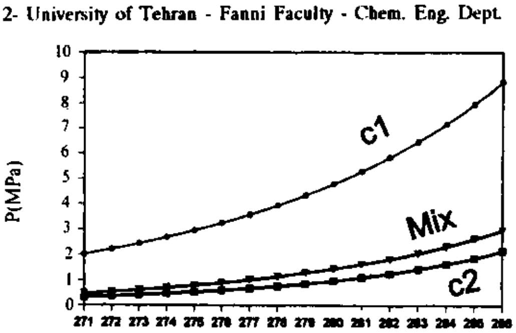

Fig. 1 - Equlibrium hydrate curve for C1 & C2 & Mixture (C1 : 92% , C2 : 6% , C3 : 2%)

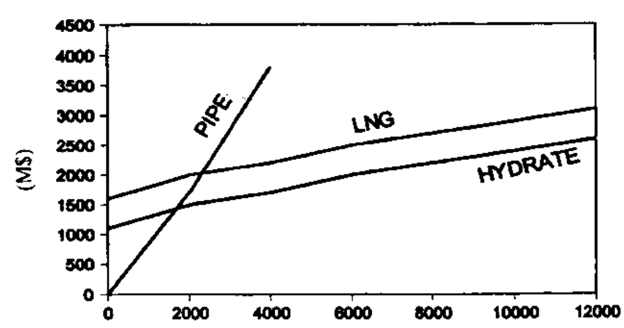

Fig. 2 - Approximate capital cost with transportation distance (Ref. 3)

Transportation of Natural Gas by Production of Gas Hydrate

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ABSTRACT

The demand for natural gas in the world is increasing and we need to find ways of cheaper and safer transportation of natural gas. The transportation of natural gas by hydrates (solid form) could be an alternative method to the more common methods such as using pipeline (gas form). 1 m^3 of hydrate can capture about 150m^3 of natural gas. Although the formation of hydrates requires high pressure condition the transportation and storage of hydrate crystal can be conducted at atmospheric conditions close to temperature of ice. Initial studies show 25% decrease in capital cost achieved using hydrates technology in comparison with that of LNG. A highpressure labratory setup has been built to provide experimental data for use in the design and development of hydrate-based process for oil and gas industry. The hydrate reactor (a bubble column) and the circulation loop operate at pressure up to 6000 psi and contant temperature in the range 0-15°C. The hydrate formation kinetics, as well as the rate of decomposition of hydrates required in gas recovery from hydrate crystals, can be studied in the above setup.

Keyword: Transportation, Natural gas, Hydrate formation kinetic

Introduction

Gas hydrates are crystalline compounds which belong to a group of solids called clathrates. They are stablised by the inclusion of suitably sized gas molecules inside cavities formed by water molecules through hydrogen bonding. In appearance they are similar to ice but unlike ice they may form at temperatures above the ice point. The host (water) molecules in hydrates structure due the hydrogen bonding form an unstabe lattice structure with several cavities and guest (gas) molecules can occupy the lattice caivties. A minimum number of cavities must be occupied by the gas molecules. Some molecules such as methane, ethane, propane, butane, carbon dioxide, nitrogen can form hydrates. The equilibrium lines for methane, ethane and a typical mixture hydrate (9% C1, 6%C2, 4%C3) are shown in Fig 1.

Gas hydrates have long been a nuisance in the production and transportation of oil and gas, and then research on hydrates has been directed primarily toward preventing of hydrates formation. The investigations have revealed that hydrates also can store hydrocarbons as much as 180 volumes of gas in a volume of hydrates. The storage properties of hydrates along with their other important characteristics have suggested their potential use as a practical means of storing large quantities of gas for commercial applications, such as:

- Hydrates for safe transportation of natural gas.
- Hydrates for clean fuels in automotive vehicles.
- Hydrates for bulk storage of gas at variable consumption rates in different seasons.

Transportation of natural gas

The demand for natural gas in the world is increasing. Large natural gas resources, are not located near the main consumption centers. The transportation of natural gas over increasingly longer distances will consequently be required. Today large scale transportion of natural gas is commonly conducted by pipelines (gas form) and by ship (liquefied form). Pipelines are used for distances up to a few thousand kilometers (about 4000 km), while transport of liquefied natural gas (LNG) by ship is used for longer distances (about 12000 km). Because of the importance of natural gas, considerable effort is directed towards lowering the transportation cost.

Investigators show only 5 percent cost reduction was possible in LNG technology in production and shipping [1]. The use of natural gas hydrates for storing and transport of natural gas is an interesting alternative to that of using other technologies.

For formation of hydrates we need high pressure and temperature close to the ice point, and it seems for transportation of gas by hydrates we must provide high pressure conditions. But researchers showed that natural gas hydrates did not decompose when stored at temperatures in the range -15 to 5°C in an ordinary freezer at atmospheric pressure near adiabatic condition because of formation a layer of ice on it [2].

Initial studies show that 24 percent decrease in capital cost by using hydrates for transportation. The approximate capital cost with transport distance is shown in Fig. 2.

The figure shows the capital costs for hydrates and LNG plants (zero distance) by adding the capital costs of ships to the plant cost, the total capital cost was obtained. The two lines diverge a little with distance because the

The think tank is actively involved in technology transfer for upstream and downstream industries from other countries such as the Russian Federation, European Union member states and the South-East Asian nations. Around 19 deals have been signed in this respect so far.

From 1991-96, the centre signed contracts with a number of universities, for educating 166 students at the MSc and PhD levels in Petroleum, chemical and mechanical engineering, and chemstry. It has also sent some PhD students abroad.

The centre is now vigorously following attempts to expand its activities and set up new research institutes. Chief among such measures include schemes for the expansion of the engineering college and the establishment of a gas research centre, a consultant-engineering firm, and the Imam Sadegh chemical township in Kermanshah.

The centres are aimed at developing technologies for industrial purposes.

Petrochemical Industry Eyes Domestic Equipment and Materials

Set up two years ago, the Supply of Parts and Engineering and Chemical Company (SPEC) has been working hard to meet the needs of domestic petrochemical companies for parts, equipment and chemical substances.

In line with the same policy, a central headquarters was formed in Tehran with subsidiary branch committee at the petrochemical plants. The committees survey the parts needed to be imported form the overseas, and gives orders to domestic manufacturers for production.

Ever since the establishment of the company, the authorities have shifted their attention to rally a collection of firms to produce parts and petrochemical materials. The SPEC has a list of companies willing for co-operation. The company conducts official visits of the interested firms to assess their facilities and negotiate ways of co-operation.

During the past two years, the chiefs of factories and the self-sufficiency committees of firms have called for supplying their needed equipment from domestic resources.

SPEC has conducted extensive studies on the materials and the know-how of the production of parts particularly through reversed engineering method. Meanwhile, contacts have been struck with some foreign parties to establish a technical company, in order to raise the quality of produced parts up to the international standards.

SPEC has on its agenda the production of parts, needed by the oil, gas and petrochemical plants, which had never been produced in Iran, or had failed to life up to the international standards.

Chief among the company's achievements in the chemical, metallurgical, mechanical, and electrical precision tools engineering are as follows:

* Produce ceramic-alumina balls for the Bandar Imam and Arak petrochemical plants
* Conduct experiments on food-grade phosphoric acid at the SR unit of the Bandar Imam petrochemical complex
* Develop and manufacture the C-702 vent gas scrubber of the Bandar Imam complex from fibre reinforced plastic
* Produce PLC for the Isfahan-Arak oil pipeline
* Launch pressure gauge tests for the internal production of the Kharg and Tabriz petrochemical plants

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