Alternatives for Natural gas Transmission from South-Pars Gas Field to India, NGH, CNG and PNG

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Abstract

The worldwide consumption of natural gas is rapidly increasing. It is predicted the natural gas demand increases at an average rate of 2.4 percent annually until 2030 in the world. However this rate of increase is higher for some countries with fast growing economy like India. To satisfy such a demand, there are some plans to transport natural gas from south pars gas field, the largest Iran's natural gas field, to India. There are many possible technologies for transporting gas from production fields to consuming markets. These technologies include pipelines (PNG), Liquefied Natural Gas (LNG), Compressed Natural Gas (CNG), Natural Gas Hydrates (NGH), Gas to Liquid (GTL), Gas to Commodity (GTC) and Gas to Wire (GTW), i.e. electricity. Gas transmission projects are sensitive to technology selection and depending on the capacity and distance; chosen technology may affect the economy of the entire project noticeably. In this work the feasibility of transporting 100 MMSCMD natural gas from port Assaluyeh in southern Iran to India using some alternative technologies such as PNG, CNG and NGH has been investigated. The results show for this case, PNG is the best cost effective method and CNG and NGH are the other options respectively.

Keywords: *Natural Gas, PNG, CNG, NGH*

1. Introduction

Natural gas is one of the important energy resources and its worldwide consumption is rapidly increasing. Recently its consumption is being accelerated because of growing environmental concerns. It is predicted the natural gas demand increases at an average rate of 2.4 percent annually until 2030 in the world [1]; however, this rate of increase is higher for some countries with fast growing economy like India. To satisfy such a demand, there are some plans to transport natural gas from south pars gas field, the largest Iran's natural gas field, to India. There are many possible technologies for transporting gas from production fields to consuming markets. These technologies include pipeline (PNG), Liquefied Natural Gas (LNG), Compressed Natural Gas (CNG), Natural Gas Hydrates (NGH), Gas to Liquid (GTL), Gas to Commodity (GTC) and Gas to Wire (GTW), i.e. electricity. However only the first four ones are known as methods, which transport gas energy as gas.

Factors influencing the feasibility of natural gas developments include the size of the resource, the distance to the market, the size of the market and the technology used. The technology used needs to be appropriate for the size of the resource.

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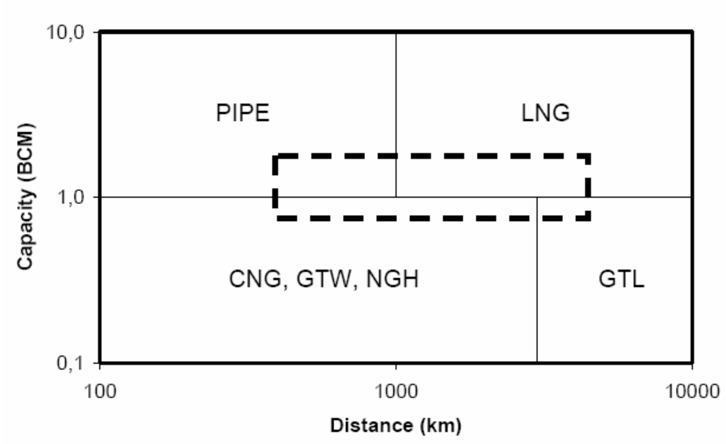

Fig.1. Capacity-Distance Diagram [1]

At present, only pipelines and LNG are the 'gas as fuel' transport routes. Pipelines are universally used to transport natural gas from field resource to market. Economy-of-scale effects influence what transport capacity and distance a particular pipeline will be feasible. The shorter the distance and larger the capacity, the more feasible a particular natural gas pipeline is. The size of the market influences the transport capacity of a particular pipeline. Furthermore, with increasing distance the feasibility of a particular pipeline decreases. The distance the feasibility of a particular pipeline becomes marginal depends on many factors. When the feasible pipeline-distance is exceeded, other natural gas transport technologies become appropriate. A capacity-distance diagram for the transport of natural gas is shown in Fig.1. The diagram illustrates what technologies are likely to be appropriated with respect to distance and capacity. LNG is generally considered appropriate for large-volumes for long-distances; GTL (gas to liquid) is generally considered appropriate for medium-to-low volumes for long-distances. CNG, GTW and NGH technologies are considered appropriate for medium-to-low volumes and medium-to-short distances. An overlap region is shown in Fig.1, to reflect the wide range of conditions that affect the gas technology selected for a particular application [2]. In this study, PNG, which is the best option for transporting natural gas in short distances, is compared to newly developed natural gas transporting methods, CNG and NGH.

2. Iran to India Gas Transportation

The composition of gas being transported is shown in Table 1. It also represents the temperature and pressure of feed gas.

Table 1. South Pars Gas Field Composition, (T=122 F°, P=1305 psia)

Component	Mole %
C_1	87.31
C_2	4.90
C_3	2.03
i-C_4	0.36
n-C_4	0.51
CO_2	1.10
N_2	3.79

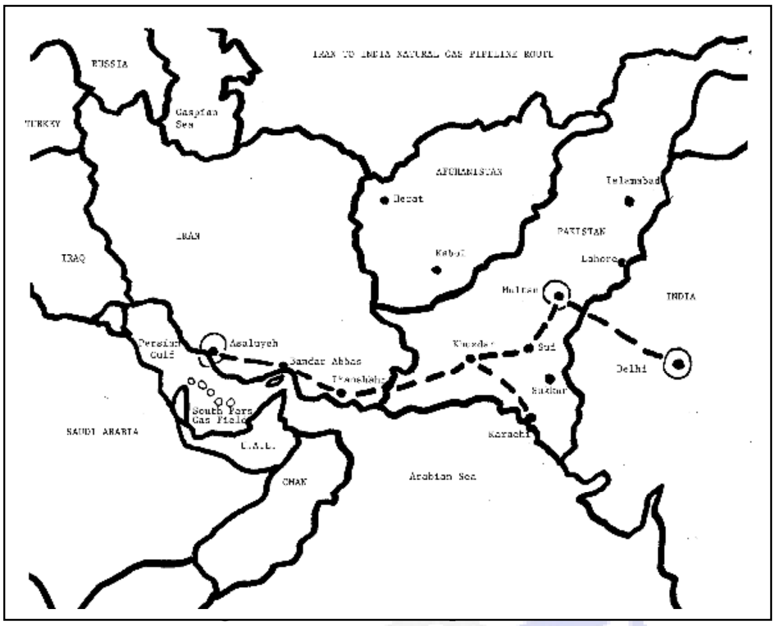

Fig.2. Iran to India Gas Pipeline Route [3]

2.1. Pipeline

In 1993, Iran proposed export of natural gas to India. Alongside this proposal was the plan to export natural gas to Pakistan as well. The Iranian government proposed the construction of a pipeline from South Pars fields in the Persian Gulf to Pakistan's major cities like Multan and then further onto Delhi, India [3]. However, in this study, we assume that Iran's gas is being to export to India and there are no any taking points along the route.

A 56$''$ pipe (5LX type, grade X70) is used for 100 MMSCMD capacity and is simulated using PIPESYS software. Fig.2 shows the pipeline's main route. The pipeline originates from *Assaluyeh,* on the coast of *Persian Gulf* near the Iranian South Pars fields. It travels to *Pakistan* through *Khuzdar* and *Multan*. From *Multan*, the pipeline travels to *Delhi*, where it ends [3]. Total length is approximately expected to be 2600 km. Soil temperature and overall heat transfer coefficient are assumed to be 20°C and 0.25 Btu/(ft^2. hr. $^{\circ}$F) respectively . Other required data are summarized in Table 2.

Table 2. Economic Items of PNG Technology

Pipeline investment cost for a NPS 56 (pressure 1305 psia)	$30000/(inch. kilometer)
Compression investment cost	$600/installed BHP
Pipeline annual O&M[a]	3 percent of PI[b]
Compression annual O&M	4 percent of COI[c]

a. Operating and maintenance cost

b. Pipeline investment cost

c. Compression investment cost

2.2. Compressed Natural gas (CNG)

In this work, the CNG "VOTRANS" concept is used to evaluate the CNG potential for transmission of natural gas. The technology is relatively simple and can be divided into three parts namely compression, refrigeration and marine transportation. The gas is pressurized to 1800 psig, after-cooled and then refrigerated to -20 °F and is transported using CNG carriers of 3.5×10^6 ft^3 capacity. Loading and unloading the compressed natural gas is done at the rate of 1000 MMSCFD and the ships will travel at 18 knots [4,5].

2.2.1. Compression

The required brake horsepower of compressors and compression stages can be calculated based on the compression ratio, volume of gas, temperatures and pressures using the following equation:

$$BHP = 0.0857\, Z_{av} \left[\frac{q_g\, T_s}{E}\right]\left[\frac{k}{k-1}\right]\left[\left(\frac{p_d}{p_s}\right)^{\left[\frac{k-1}{k}\right]} - 1\right] \qquad (1)$$

The cost of compressors after-cooled with air-coolers are in the range of $550-600 per installed BHP, while compressors using sea water as cooling medium cost $1000-1300 per installed BHP. In this study air cooled compressors are used for economic evaluations. It is also assumed that for these compressors the operating cost is about $0.06/kw.hr [5].

2.2.2. Refrigeration

Power required to cool the compressed gas to -20 °F can be estimated from the following equation [5]:

$$BHP_{ch} = Q_{ch} \times h \qquad (2)$$

Where, Q_{ch} is the heat duty of refrigeration in Btu/hr and h is a conversion factor. The factor ranges from 1.89 to 1.63 depending upon the number of stages. Table 3 shows the cost of chilling in $/BHP for both air-cooled and water-cooled compressors based on number of stages used. It is concluded that two-stage refrigeration is the most cost–effective.

2.2.3. Marine Transportation

The main onshore loading infrastructures include compressor and its accessories and the chillers are on board. The ships carry the chilled compressed gas in a box-like structure called CNG module. The number of ships required for transporting CNG from port Assaluyeh to port Hazira in India (2350 km), depends upon the loading rate, voyage distance and time required for a ship to make a complete cycle of loading gas on the ship, transporting it, unloading the cargo at the buyer side and returning to the origin. The cost of CNG carriers of 3.5×10^6 ft^3 capacity is assumed $ 230 million and for operating and maintenance cost, a value of $30million/ship.year is assumed in the economical model [4,5].

Table 3. Cost of Chilling in $/BHP for Both Air-cooled (a) and Water-cooled (b) Compressors Based on Number of Stages Used

Stages	h	$\$/BHP_{ch}{}^{a}$	$\$/BHP_{ch}{}^{b}$
1	1.89	1361	2268
2	1.71	1334	2223
3	1.63	1369	2282

2.3. Natural Gas Hydrates (NGH)

Gas hydrates are ice-like solids formed by the physical combination of water and gas molecules. The natural gas molecules are trapped in the cavities of the ice-like crystalline molecular structure. Theoretically, 170 Stdm^3 of methane gas can be concentrated in 1 m^3 of water. Hydrate chain can be divided into production, storage and marine transportation [6].

2.3.1. Hydrate Production Process

The process for production of NGH is shown in Fig.3. This process scheme is based on the process proposed by Javanmardi et al [7]. The volumetric flow rate of natural gas per train was assumed 25 MMSCFD. The dryer acts as a heat exchanger and a pre-cooler for the natural gas stream. The gas stream leaving the dryer is fed to the reactor. The fresh water which is assumed to be pure at this stage is also pumped to the reactor at 27 $^{\circ}$C. In the reactor the heat of hydrate formation is removed. The slurry of the natural gas hydrates and free water then are fed to the separator. The free water after separation is recycled to the reactor. The free water content of the water-natural gas hydrate slurry fed to the dryer is assumed to be 12 wt%. It has been investigated that to transport the natural gas hydrate at atmospheric pressure, the temperature of the hydrate slurry should be lowered to about -15 $^{\circ}$C. The heat of hydrate formation and cooling duty of the heat exchanger are removed using a refrigeration cycle as indicated in Fig.4. Propane is used as refrigerant in this process. Approach temperature equals to 6 $^{\circ}$C in the heat exchanger and condenser and seawater (27 $^{\circ}$C) is used as heat sink in the condenser. The reactor, heat exchanger, dryer and condenser duties are estimated using mass and energy balances for each unit of the hydrate production process. The compressor power and the temperature and pressure of each stream are then calculated. Shortcut methods given by Douglas are used for economic evaluation of this section [8].

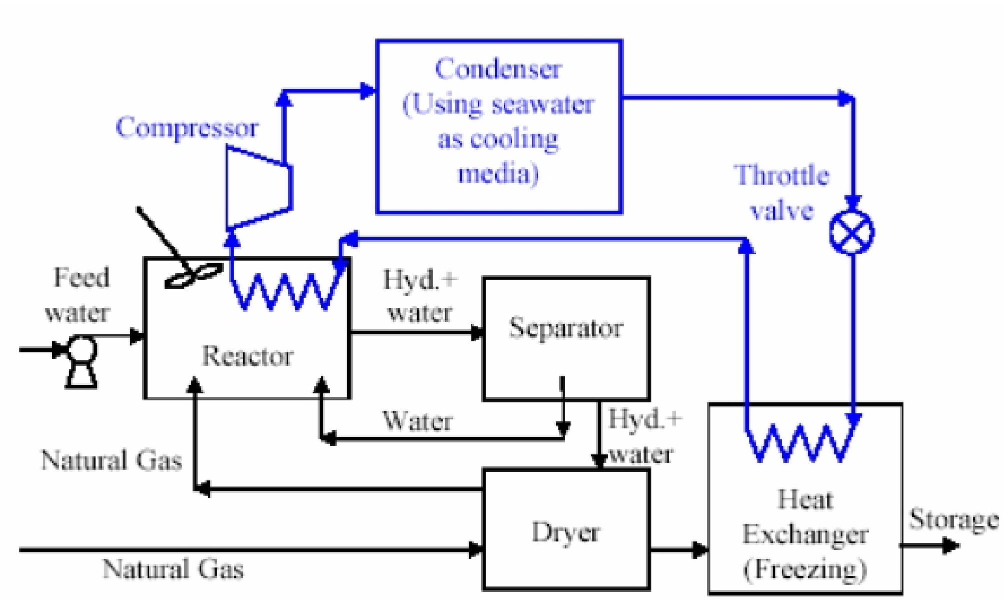

Fig.3. The Proposed Process for Production of Natural Gas Hydrates [6]

2.3.2. Storage
Assuming 7 days uncertainty in the arrival of ships to the port, the storage tanks were assumed to have a capacity of 7 days working of the plant. Taking 40000 m^3 as the capacity of each tank [7], the total number of tanks is estimated.

2.3.3. Marine Transportation
The NGH ships can be built to carry about 250000 m^3 of hydrates. Moreover, 1 m^3 of solid methane hydrate, with 100 percent void occupancy by methane, will release roughly 170 m^3 of methane. Therefore, the capacity of the NGH ships can easily be calculated. The average speed of the NGH carriers has been reported 15.4 knots [7]. Shipping distance from port Assaluyeh to port Hazira is about 2350 km. The time for loading, unloading and waiting period for each ship per each round trip has been assumed to be 12 days. Based on these data, the required number of NGH ships can be estimated. The capital cost of the NGH ships has been reported to be $80 million per ship. In this work, operating and maintenance cost (O&M) of the hydrate shipping is estimated $12 million per year per ship [7].

3. Economic Model
The economic model used in this study, compares the three transport options based on a total product cost method which is calculated as follows:

Total product cost = Amortized total capital investment + Amortized O&M (3)

Assuming 20 years as a useful life of the plant and continuous discount rate, i, equal to 8%, the amortized total capital investment is obtained by:

$$Amortized\ tot.inv. = \frac{\dfrac{\exp(0.08\times 20)}{\sum_{i=1}^{19}\exp(0.08\times 20)}}{365\times capacity}\times Tot.Inv. \quad (4)$$

The amortized O&M (operating and maintenance costs) is calculated from:

$$Amortized\ O\ \&\ M = \frac{Total\ O\ \&\ M}{capacity} \quad (5)$$

4. Results

The calculated values for the most important parameters for each alternative are summarized in Table 4.

Table 4. Design Specifications for each Technology

PNG	
Power consumption for compression	1195176 BHP
CNG	
Power consumption for compression	654234846 BHP
Power consumption for refrigeration	105385 BHP
Number of ships required	29
NGH	
Number of production trains in parallel	141
Number of storage tanks	103
Number of ships required	53

Based on the mentioned economic model and using all the data, total product cost of transporting 100 MMSCFD gas to India was estimated. Calculations are based on a feed gas price of $0.5/MMBTU. Results are summarized in Table 5.

Table 5. Economic Evaluation Results for each technology

Technology	Total Capital Investment $MM	Total O&M $MM/year	Total Product Cost $/MMBTU
PNG	5113	837	0.99
CNG	6997	1628	1.79
NGH	15222	2415	2.90

5. Conclusions

Natural gas is one of the most important energy resources and its worldwide consumption is rapidly increasing. The rate of increase is higher for some countries with fast growing economy like India. To satisfy such a demand, there are some plans to transport natural gas from south pars gas field, the largest Iran's natural gas field, to India.

In this work, newly developed technologies of CNG and NGH, are compared to the most common method PNG for transporting 100 MMSCFD of natural gas from Assaluyeh to India. After designing and simulating the processes and doing economic evaluations, it is concluded that based on the total product cost, PNG is the most cost effective method. NGH has the largest capital investment and operating costs with respect to others. However this technology is under feasibility study and it is not on the stage of implementation yet.

List of Symbols

BHP	Brake Horse Power
k	Gas Exponent C_p/C_v
MMSCFD	Million Standard Cubic Feet per Day
MMBTU	Million BTU
p	Pressure psia
q	Gas Flow Rate, MMSCFD
Z	Compressibility Factor

Subscripts

av	average
ch	chiller
d	discharge
g	gas
s	suction

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