Petroleum and Coal

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Methane Hydrates for Natural Gas Capture and Transport of Natural Gas in Nigeria

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Received September 24, 2020; Revised December 30, 2020; Accepted January 15, 2021

Abstract

Methane hydrates are produced when natural gas is blended properly with chilled water to yield a stable water crystalline ice-like structure. 1 m^3 of methane hydrate produced will contain about 160 sm^3 gas (5,600 scf) and 0.85 m^3 water at pressures > 50 bar and temperatures ≤ 10ºC in the presence of water and natural gas. This can be used to capture and transport large volumes of natural gas at atmospheric pressures thereby solving the problems surrounding flaring of associated gases in the Niger Delta region of Nigeria while also providing a means of harnessing natural gas in stranded and marginal fields. This paper discusses methane hydrates as a more viable option for gas capture and transport in the Nigerian oil and gas industry. Methane hydrate technology can be applied in regions in the Niger Delta where associated gases are prone to flaring thereby reducing routine gas flaring activities. It can also be used to harness natural gas present in stranded and marginal fields. Studies show that a methane hydrate chain is 25% lower in capital cost than an LNG chain. In terms of transport distance for natural gas, methane hydrate is best and appropriate for medium to short distances. A major drawback to its suitability in the Nigerian context is applicability only for medium to short distances of transportation.

Keywords: *Natural gas; Transportation; Methane hydrates; Gas utilisation; Nigeria.*

1. Introduction

Natural gas is a highly economic hydrocarbon that has become a major energy commodity due to its usefulness for electricity generation in power stations, heating energy for homes and fuel for fixed engines or in motor transport. It is also a chemical feedstock or an energy source for manufacturing commodities with a large energy requirement [1]. Generally, natural gas can be obtained as an associated gas which is produced alongside with crude oil from a well as the reservoir pressure drops or as a non-associated gas produced from reservoirs having only natural gas [2]. Natural gas can also be obtained from stranded and marginal fields, in this case, they are referred to as stranded gases or marginal gases respectively. The term stranded gas is used for situations where the field to be produced is remote or located in deepwater regions, the term marginal gas is used for situations where the field to be produced is too small to justify a gas pipeline for long-term production [3].

In 2018, the global natural gas consumption rose by 96 billion cubic metres (bcm) or 3%, this is recorded as the fastest growth since 2010 also natural gas trade expanded by 63 billion cubic metres (bcm) or 6.2% [4]. However, the World Bank Global Gas Flaring Reduction (GGFR) Partnership has reported that Nigeria is the 7th highest gas flaring country in the world with about 800 MMscf of gas being flared daily from approximately 144 gas flare points across the country [5].

The Nigerian government is committed to ending routine gas flaring in the Niger Delta [5-6] and unlocking the gas potential of the country through her Nigerian Gas Flare Commercialisation Program (NGFCP) as launched on 13 December 2018 by the Nigerian National Petroleum Commission, NNPC [7-8]. This program aimed to provide a commercial approach for the elimination of routine gas flaring by 2020 [9]. A major setback to the success of this program is the high cost of gas capture and transport facilities and the need for an economics of scale. The currently available options include the use of pipelines, liquefied natural gas (LNG), compressed natural gas (CNG), gas to liquid (GTL) and the use of methane hydrates. Indigenous researchers have recently started to explore ways to solve the Nigerian gas problem both at the transportation and utilisation stage [10].

This paper discusses methane hydrates as a more viable option for gas capture and transport in the Nigerian oil and gas industry. The papers first discuss the current methods and forms in which natural gas is transported. An overview of methane hydrates is first presented then the elaborations on the processes involved in its capture and transport is further discussed. A comparison of alternatives for methane hydrates for gas capture and transport in the Nigerian oil and gas industry is then discussed.

2. Current methods of transporting natural gas

2.1. Pipelines

This involves transporting natural gas through a welded steel pipeline that is similar to an oil pipeline. As a way of moving gases and liquids over large distances from their sources to the final customer, pipelines play an incredibly important role in the world [11]. They are very convenient in gas transport but are not flexible in operation because the gas transported will leave the source and arrive at only one end [2], this is rather uneconomic for small reserves. The problem of pipeline vandalism is still a subject of great concern especially in hostile communities in the Niger Delta [12-13].

2.2. Liquefied natural gas (LNG)

This involves transporting natural gas in its liquid form by cooling to around -162ºC with the aid of huge cryogenic LNG facilities requiring complex machinery which are very expensive to operate [14]. Hence, LNG cannot be used to supply gas to smaller markets due to the high cost required for operation. It is most suitable for large volumes of gas and most appropriate for long-distances [15].

2.3. Compressed natural gas (CNG)

This involves transporting natural gas in containers operating at high pressure ranging from 1800 psia for rich gas content (significant trace of ethane, propane etc.) to roughly 3600 psia for lean gas content (majorly methane) [16]. The CNG systems can be adopted for smaller fields such as marginal fields and can make transport possible for stranded gases [14].

2.4. Gas to Liquid (GTL)

This involves transporting natural gas by first converting it to a liquid through a catalysed chemical reaction [17]. Natural gas can be converted into syn-crude, methanol, naphtha etc. and at such transported. The most common conversion of this natural gas is to methanol through the Fischer-Tropsch (F-T) synthesis [18] which involves a complex chemical plant operation with a novel catalyst [19].

2.5. Methane hydrate

This involves transporting natural gas as a solid mixture of natural gas and water known as methane hydrates [20]. This method is very attractive for fields that are relatively close to the market as the gas will be reduced by about 160 times under attainable temperature and associated pressures, this methane hydrates also has a low melting rate indicating a minimal gas loss during transport [21].

3. Description of methane hydrate

Methane hydrates are produced when natural gas is blended properly with chilled water to yield a stable water crystalline ice-like structure. There are however four conditions it must satisfy simultaneously for its formation to occur: the presence of chilled water, natural gas, high pressure (HP) and low temperature (LT) [15].

A well-formed methane hydrate will contain about 160 sm^3 gas (5,600 scf) and 0.85 m^3 water per 1 m^3 of the hydrate mixture [1], another major advantage of storing gas in the methane hydrate state is that high volumes of gases are stored at relatively low pressures of > 50 bar while at normal temperature of ≤ 10°C. The transportation of methane hydrates is carried out using an insulated cargo usually operating at around -5°C at atmospheric pressure or 0°C at 10 bar [14].

This methane hydrate cage (Fig. 1) is made up of several water molecules that are held together by hydrogen bonds with certain small molecules such as methane, ethane and propane stabilising the hydrogen bonds to form a 3D cage-like structure having the small gas molecules trapped within the methane hydrate cage [22]. These structure types are known as clathrates and it occurs in three different types of cage structure for water molecules to hold different sized molecules. They include sI caged molecules containing 46 water molecules holding 8 gas molecules, sII caged molecules containing 136 water molecules holding 24 gas molecules and sH caged molecules containing 34 water molecules holding 6 gas molecules [23].

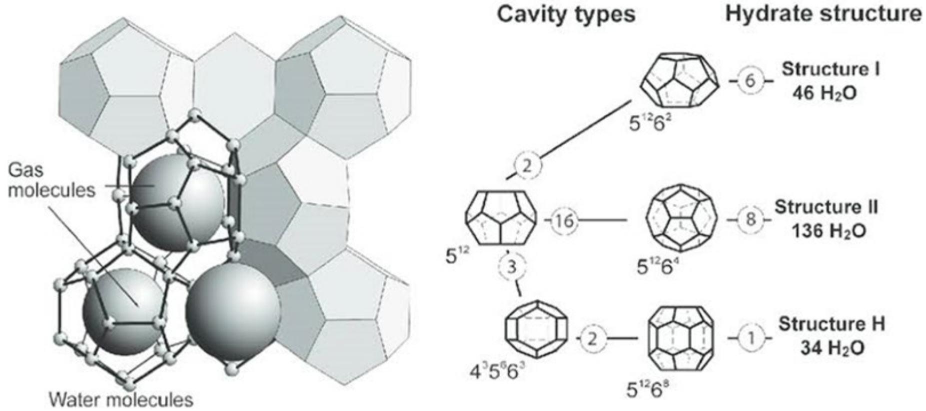

Fig. 1. Cage structure of methane hydrate

The conditions of pressure and temperature required for methane hydrate formation depends critically on the water and gas composition in the mixture. This can be determined with the aid of a methane hydrate equilibrium curve as shown in Onwukwe and Duru [15]; the equilibrium lines differentiate the conditions in which the methane hydrate will be stable from the condition where the methane hydrate will be dissociated in a free system [15]. It can be observed that at higher pressures above the equilibrium lines the methane hydrates remain stable and will only dissociate at conditions beneath the lines.

4. The methane hydrate capture and transport process

The process of capturing and transporting natural gas as methane hydrates involves several stages of operations as shown in Fig. 2. The first stage is the natural gas processing where it is treated before being sent for methane hydrate production. The methane hydrate is then transported, stored and later converted for utilisation. More details of each stage of the process are given in this section.

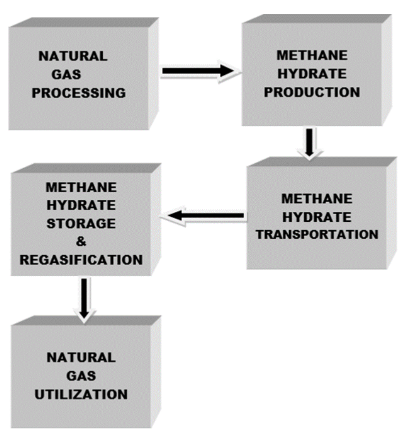

Fig. 2. Stages of operation in methane hydrate capture and transport

4.1. Natural gas processing

The processing of natural gas begins at the well-head and it involves the removal of common contaminants such as carbon dioxide (CO_2) and hydrogen Sulphide (H_2S) in the natural gas mixture. Natural gas is termed "sweet gas" when it is relatively free of H_2S and "sour gas" if it contains H_2S. The water content of the gas is not hydrated.

4.2. Methane hydrate production

The production of methane hydrate can be carried out using a mobile tank reactor in which the gas is blended with chilled water, the gas entering the reactor is cooled and compressed to temperatures ≤ 10°C and pressures > 50 bar depending on the temperature and phase diagram. After the formation of methane hydrates, the excess water and gas in the mixture are recycled and the formed hydrate is cooled, depressurised and compacted to make it more stable [14].

4.3. Methane hydrate transportation

The transportation of methane hydrate from the production site is carried out using an insulated freezer truck having about 100 mm of insulation for onshore facilities and operating at around -5°C at atmospheric pressure or 0°C at 10 bar [14]. The methane hydrate can be loaded into the insulated freezer truck using a covered mass conveyor.

4.4. Methane hydrate storage and regasification.

The storage of natural gas in the solid state as methane hydrates could occur using large storage tanks maintained at a temperature around -5°C at atmospheric pressure, this has been proved in the laboratory for several months yielding a minimal loss of gas. Regasification of methane hydrate is carried out under controlled application of heat using water to provide enough energy to dissociate the hydrates into gas and water. The separated natural gas is dehydrated in an ethylene glycol absorption unit for adequate removal of the water content [14].

4.5. Natural gas utilisation.

The natural gas obtained can be used for power generation in gas-fired thermal power plants across the country, it is also a fuel for fixed engines or in motor transport and it is also a feedstock for several chemical industries [1]. The proper utilisation of natural gas in Nigeria will boost the nation's revenue and will lead to the elimination of routine gas flaring in the Niger Delta.

5. Comparison of alternatives

In Nigeria, the most common method of transporting natural gas to the domestic market is through the use of pipelines, whereas the method used to transport natural gas to the international market is through the Liquefied Natural Gas (LNG) technology produced the Nigerian LNG company in Bonny, Rivers State. There are other alternatives for transporting natural gas to the market either domestically or internationally. All the methods involved in natural gas transport will be discussed accordingly concerning the capital cost (CAPEX) for the facility set-up and the capacity-distance relations.

5.1. Capital cost for facility set-up

For pipelines, the capital cost required to construct pipelines depends on factors such as distance, pipeline coverage, the terrain of the region, required compression, the diameter of the pipe and onshore or offshore considerations. Also, after the installation of the pipelines, annual costs come into consideration to cater for compressor station maintenance and fuel cost [24]. Generally, the cost associated with a pipe project is between $600,000 and $4,000,000 per kilometre [14]. It can be assumed that offshore pipelines are 50% more expensive to build than onshore pipelines [25-26].

For LNG, the capital cost allocation for facility set-up is 50% for liquefaction, 39% for shipping and 11% for offloading as shown in Economides *et al.* [27]. From the allocation, the liquefaction plant section has the largest share of 50%, the costs involved include compressors, exchangers and refrigerants. The next largest share is the shipping section which includes the cost of the LNG vessels. The offloading section involves the costs of regasification plants and storage tanks.

For CNG, the capital cost for facility set-up is predominantly on the cost of shipping which is 89% of the capital cost allocation followed by offloading (6%) and compression (5%) which was presented by Economides *et al.* [27]. This shipping cost is directly related with the cost of materials used to design the ship which however depends on the storage efficiency, optimal pressure selection, temperature control and shipping materials. The other costs involved are compression costs and offloading costs.

For GTL, the capital cost is dependent on the location, construction and labour costs, due to the highly complex nature of GTL facilities a huge capital with access to low-cost gas feedstock is required. A 75,000 b/d plant would cost about $1.5 Billion to set-up [28], where the processes are highly dependent on the construction costs, market prices of produced liquids, product types and yields.

For methane hydrate, the capital cost is approximately 25% lower than the capital cost of Liquefied Natural Gas, LNG [29]. Similarly, the payback period on such investment will be shorter for methane hydrate technology than for LNG [1], also when methane hydrate is compared to other alternative methods of transporting natural gas it is safer, less expensive to set-up, eco-friendly, easily scalable and operates in a flexible procedure that does not require complex processes or extremes of pressures or temperature.

5.2. Capacity-distance relations

The capacity-distance diagram for the various methods of natural gas transportation was shown by Onwukwe and Duru [15]. From their diagram the following relations can be made: LNG is considered most appropriate for large volumes and long distances; GTL is considered most appropriate for medium-to-low volumes and long distances; Pipelines are considered most appropriate for large volumes and distances less than 1,000 km in length, CNG and Methane hydrates (Also known as Natural Gas hydrates, NGH) are considered most appropriate for medium-to-low volumes and medium-to-short distances. The region that overlaps all the described methods of natural gas transportation accounts for the wide range of conditions that could affect the selected method of transporting natural gas for a specific application either domestically or internationally [15].

6. Conclusion

In this work, methane hydrate is presented as a more viable method of capturing and transporting natural gas in Nigeria. This is due to its ability to store high volumes of gas in the methane hydrates state at relatively low pressures in a safe, eco-friendly, less expensive, easily scalable and flexible procedure that does not require complex processes or extremes of pressures or temperatures. The capture and transportation of natural gas as methane hydrates undergoes five major stages of operation namely; Natural gas processing; Methane hydrate production; Methane hydrate transportation, Methane hydrate storage and regasification and Natural gas utilisation. Despite the benefits of utilising pipelines, liquefied natural gas (LNG), compressed natural gas (CNG) and gas to liquid (GTL) for gas capture, methane hydrates remains a more viable option due to its ability to store high volumes of gas in the methane hydrates state at relatively low pressures in a safe, eco-friendly, less expensive, easily scalable and flexible procedure that does not require complex processes or extremes of pressures or temperatures thus boosting Nigeria's revenue from the utilisation and monetisation of the harnessed natural gas. Methane hydrate technology can be applied in regions in the Niger Delta where associated gases are prone to flaring thereby reducing routine gas flaring activities. It can also be used to harness natural gas present in stranded and marginal fields. Studies show that a methane hydrate chain is 25% lower in capital cost than an LNG chain. In terms of transport distance for natural gas, methane hydrate is best and appropriate for medium to short distances. A major drawback to its suitability in the Nigerian context is it's applicability only for medium to short distances of transportation.

Disclosure statement

Conflict of Interest: The authors declare that there are no conflicts of interest. This article does not contain any studies involving human or animal subjects.

Acknowledgements

The authors will like to specially appreciate Mr Justice O. Derefaka – Program Manager; Nigerian Gas Flare Commercialisation Programme (NGFCP) for his support in the provision of valuable and accurate resource materials for the success of this work.

Nomenclature

BCM	*billion cubic metre*	*GTW*	*gas-to-wire*
CAPEX	*capital expenditure*	*HP*	*high pressure*
CNG	*compressed natural gas*	*LT*	*low temperature*
F-T	*Fischer-Tropsch*	*NGH*	*natural gas hydrate*
GTL	*gas-to-liquid*		

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