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Review

Prospect of harnessing associated gas through natural gas hydrate (NGH) technology in Nigeria

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Natural gas hydrate (NGH) technology is a feasible alternative to capture associated-gas, which are usually difficult to harness in the stranded and/or marginal oil field. The importance of gas hydrates is related to its potential to be able to contain about 160 Sm^3 of gas and 0.85 m^3 of water in 1 m^3 of gas hydrate at standard temperature and pressure. This feature of natural gas hydrate can be brought to bear in harnessing associated gas instead of being flared. This article examines the prospect of natural gas hydrate (NGH) technology as a sustainable means of capturing associated gas from stranded and marginal oil field of the Niger Delta. Such gas is ordinarily being flared due to lack of adequate facilities to harnessing it. The conversion of associated-gas to hydrate will contributes to the elimination of flared gas and reduces the environmental pollution associated with gas flaring, and also increases government revenues from the monetized gas.

Key words: Natural gas hydrate, associated gas, gas flaring, hydrate slurry.

INTRODUCTION

Harnessing the potential of stranded gas has been a challenge in over 50 years of oil and gas exploration in Nigeria. Many of the Nigeria's oil fields were developed in the 1960s, without adequate infrastructures to harness associated-gas produced with the oil, thereby subjecting the gas to flaring.

Other reasons hindering the harnessing of associated-gas from oil field may include various reasons such as:

1. The field is remote and/or located in deepwater (e.g. stranded gas).
2. The field is too small to justify a gas pipeline for long-term production (marginal).
3. Inadequate pressure to transmit associated-gas at surface facility, thereby requiring booster stations.
4. Lack of application of adequate technology.
5. Weak legislature to restrict flaring of associated gas.

Prior to 1999, exploration for gas in Nigeria was limited as much of the gas is flared. It has been noted that about 1000 scf of gas is produced with every barrel of oil (Egbert, 1998). The World Bank (2007) noted that through gas flaring about $2.5 billion in government revenues is lost annually, which translates to $100 billion for the period 1970 to 2010. Recognizing the huge financial loss resulting from the flaring of associated gas and the resultant environmental damage, the Government of Nigeria promulgated the Associated Gas Re-injection

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Act and the Associated Gas Re-injection (Amendment) Act in 2004, which obligated all oil producing companies in Nigeria to submit detailed plans for gas utilization. The Government's target is to attain zero flaring by 2008 in order to reduce pollution and monetize its gas reserves. Unfortunately, this target was never met. Gas flaring is still a continuing feature in the Niger delta oil field of Nigeria

The challenge is in the absence of adequate infrastructure and lack of effective transmission and distribution network system to facilitate domestic gas utilization within the country. For decades, getting gas to market has been problematic and has prevented the development of many fields. The Nigeria oil industries has apparently come to a point where new field developments will not be undertaken unless the associated gas can be harness instead of being flared. This paper therefore discusses the potential prospect of harnessing gas energy from stranded and/or marginal oil field through the natural gas hydrate (NGH) Technology.

STRANDED AND MARGINAL OIL FIELD PROBLEM

Oil production and exploration are maturing rapidly in the Niger Delta oil field. Many new discoveries have become remarkably smaller, located in more remote areas, and are more challenging to exploit. The decrease in resource sizes and the increased distances to existing infrastructures give high development costs, and often a marginal return on investments. For such marginal fields, cost-effective solutions have to be sought for both field development and for fluid transport.

Handling the gas associated with the produced oil is an important challenge when developing marginal field discoveries. When the discovery is in the vicinity of other fields, the already existing infrastructure might be used for transportation of the associated gas. However, in lack of capacity, other ways of handling the gas must be found. In many cases the gas may be close to markets, but the reserves are too small to justify large investment for a gas pipeline. Possible options of handling such gas are either by flaring or re-injection of the gas into the reservoirs for disposal of the gas, thereby the potential revenue in the gas is not exploited.

An important alternative option is to convert the gas into a phase that can be more readily transported to market. This has an important resource aspect, as the gas may be captured and utilized.

GAS FLARING AND ENVIRONMENTAL EFFECT

Gas flaring is defined as the burning of natural gas that is associated with crude oil when it is produced to the surface. Flaring is employed to get rid of the associated gas for lack of utility and/or lack of means to get it to the consumer market.

For about fifty years gas has been flared in Nigeria (Figure 1). Nevertheless there has been sustained effort by Government and oil companies to significantly reduced gas flaring, but Nigeria is still one of the top gas flaring countries after Russia (Figure 2).

The flares have also been one of the biggest single contributors globally to climate change over the decades (Oil Change International, 2011). Gas flaring affects the health of the local communities; poison the air and light up the night sky. Impacts of gas flaring include the deposition of particulate matter, sulphur dioxide, nitrogen dioxide and carcinogenic volatile organic compounds such as dioxin, benzene and toluene. For communities next to gas flares, the toxic cocktail may have serious health impacts in the form of respiratory illnesses, asthma, cancer, painful breathing and chronic bronchitis, among others. Flared gas has also been identified as a cause of acid rains that pollute creeks and streams, damage vegetation and corrode roofs of homes. The acid rain results when sulphur and nitrogen oxides mix with moisture in the atmosphere (ERA/Friends of the Earth, 2008).

TRANSMISSION OF GAS ENERGY

Natural gas at the wellhead is usually gathered in the field and processed to flow stat ion. There are a number of methods of transmitting gas energy from an isolated field for use elsewhere. These includes: Pipelines, compressed natural gas (CNG), liquefied natural gas (LNG), gas to liquid (GTL), gas to wire (GTW), and natural gas hydrate (NGH). These respectively involve:

1. Compressing and transporting gas via buried, welded steel pipeline similar to oil pipeline.
2. Using unique steel containers to receive compressed gas to be delivered to a shore terminal designed to handle gas of this disposition.
3. Chilling methane gas to (-162°C) and liquefied for easy transportation.
4. Gas is chemically treated in a manner that converts it to liquid hydrocarbons at ambient temperature to facilitate its conveyance.
5. Produced gas from the oil fields could be used as fuel for electricity generation at or near the reservoir source and transported by cable to nearby destination(s).
6. Stranded gas may be converted to hydrate to facilitate its conveyance (NGH).

It is useful to provide some comparison among the various natural gas conveyance methods. Figure 3 show that LNG is generally considered appropriate for large-volumes for and long-distances; GTL is generally considered appropriate for medium-to-low volumes and long-distances. Pipelines are suitable for less than 1000 km in length and are generally considered appropriate for large-volumes. CNG, GTW and NGH technologies are

Figure 1. Flaring of associated gas from oil well in Nigeria.

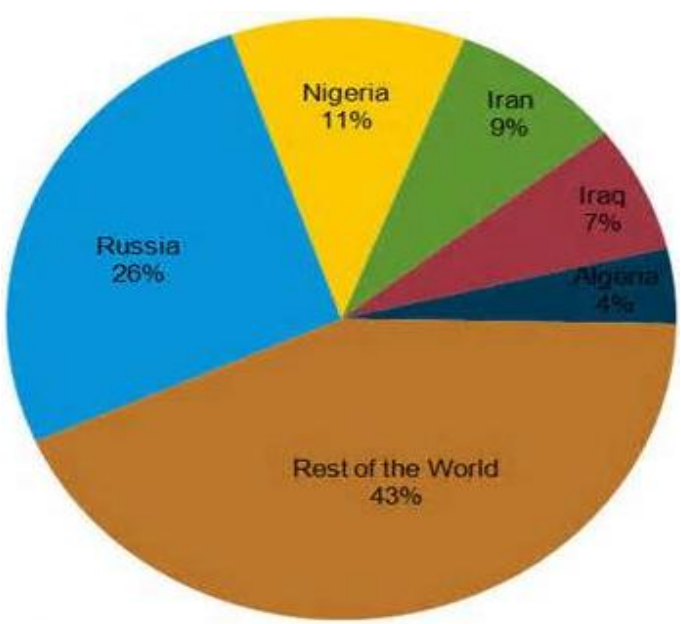

Figure 2. Top five gas flaring countries, 2010. Source: National Oceanic and Atmospheric Administration (NOAA).

considered appropriate for medium-to-low volumes and medium-to-short distances. The overlap region shown in Figure 3 reflects the wide range of conditions that affect the gas conveyance technology selected for a particular application.

NATURAL GAS HYDRATE CONCEPT

Gas hydrates are crystalline substances composed of water and gas in which a solid water-lattice accommodates gas molecules in a cage like structure, forming a stable snow-like substance. It is created when certain small molecules, particularly methane, ethane and propane, stabilize the hydrogen bonds within water to form a 3-dimensional cage like structure with the gas molecules trapped within the cages, shown in Figure 4.

Gas hydrates form as a result of the Van der Waals attraction between the molecules. Four conditions must be met simultaneously, in order for the gas hydrate to form: presence of gas, water, high pressure and low temperature.

A well formed hydrate may contain about 160 Sm^3 gas (5,600 scf) and 0.85 m^3 water per 1 m^3 of hydrate (Dawe et al., 2003). This unique feature of natural gas hydrate is an attractive alternative for capturing associated gas produced from stranded and marginal oil fields, hence allowing for effective storage and transport of associated gas in form of hydrate.

Various processes of producing hydrates have been proposed and tested in the laboratory (Gudmundsson and Mork, 2001), with the variations being a hydrate consisting of a dry powder and oil-based slurry.

Dry hydrate

The initial focus of the hydrate technology programme was on bulk gas transportation with the technology being deployed as either floating offshore or coastal onshore facilities. The basis of dry hydrate process is to produce a white, snow-like dry solid hydrate in a series of continuously stirred hydrate formation reactors. Gas from conventional oil and gas processing facilities provides the feedstock to the hydrate production plant.

The principal advantage of the dry solid hydrate, which

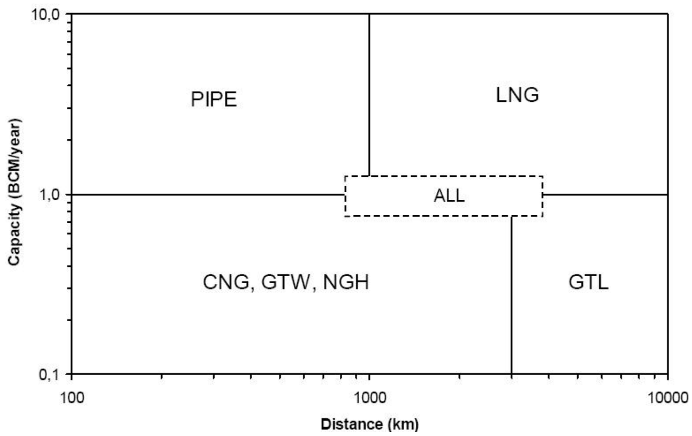

Figure 3. The capacity-distance diagram (Gudmundsson and Graff, 2001).

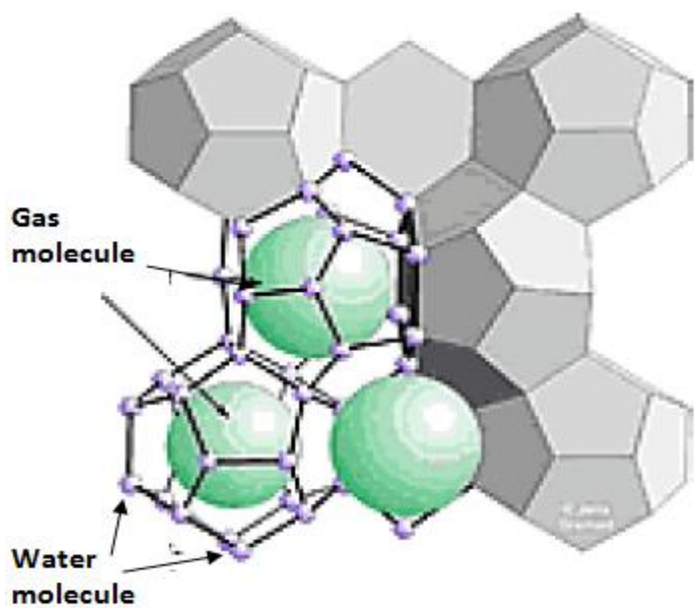

Figure 4. Structure of gas hydrate.

can be conveyed pneumatically, is that it can be stored and shipped at sub-zero celsius temperatures without problems of freezing free water.

Hydrate slurry

The concept of hydrate slurry is a simplification of the dry hydrate process. The slurry process has been developed to manage associated gas in areas lacking gas infrastructure and/or market thereby allowing the value of the gas, that otherwise would have been stranded, to be unlocked and offer a real and viable alternative to flaring and reinjection.

HARNESSING ASSOCIATED GAS VIA HYDRATE SLURRY

In the hydrate slurry concept, the ability of natural gas hydrates (NGH) to store gas is utilized. Produced under the right conditions, NGH contain theoretical about 160 Sm^3 gas per m^3 hydrate. This means that 160 m^3 of natural gas at standard condition (1 bar, 15°C) will be released upon melting 1 m^3 of natural gas hydrates.

In the hydrate slurry concept, the associated gas is contacted with liquid water at hydrate forming conditions, typically 60 to 90 bar and 2 to 10°C. The resulting solid hydrates are subsequently mixed with the refrigerated crude oil or condensate to create oil-hydrate slurry. Alternatively, the oil-hydrate slurry can be produced directly by contacting the gas with an emulsion of water droplet in oil at hydrate forming conditions. The oil-hydrate slurry might be refrigerated to temperatures below 0°C, and de-pressurized to atmospheric pressure. The refrigerated slurry can be transported in insulated, low pressure shuttle tankers. Alternatively, the slurry can be transported under high pressure in pipelines (Gudmundsson et al., 1998, 1999a, b). A simplified flow diagram of the hydrate slurry process is shown in Figure 5.

The hydrate slurry concept makes it possible to capture the associated gas and co-transport it with the crude oil/condensate to a processing plant on land, at moderate low temperatures and at atmospheric pressures. At the receiving terminal, the slurry is heated to melt the hydrate, and the mixture is separated into gas, oil, and water (Figure 6).

HYDRATE EQUILIBRIUM CONDITION

The pressure and temperature conditions for hydrate formation depend on the water composition, and the gas composition. Statistical thermodynamics computer programs are commercially available to calculate the hydrate formation equilibrium pressure for a gas and a water phase, given the temperature, or vice versa. Several experimental programs have confirmed the results from these computer programs (Sloan Jr., 1998). Figure 7 shows a hydrate equilibrium curves (Andersson and Gudmundsson 1999), developed with the aid of a computer program to calculate the hydrate equilibrium lines for two gases; methane and a gas mixture. The equilibrium lines separate the conditions where hydrate will be stable from the condition where the hydrates will dissociate in a free system. At high pressure, above the equilibrium lines, the hydrates will be stable. The hydrates will dissociate at conditions beneath the lines. Hence, NGH technology basically converts gas into hydrates and transport it as slurry in a liquid phase, thereby providing solution for gas utilisation for fields where the ambient temperature and pipeline pressure are inside the hydrate equilibrium conditions.

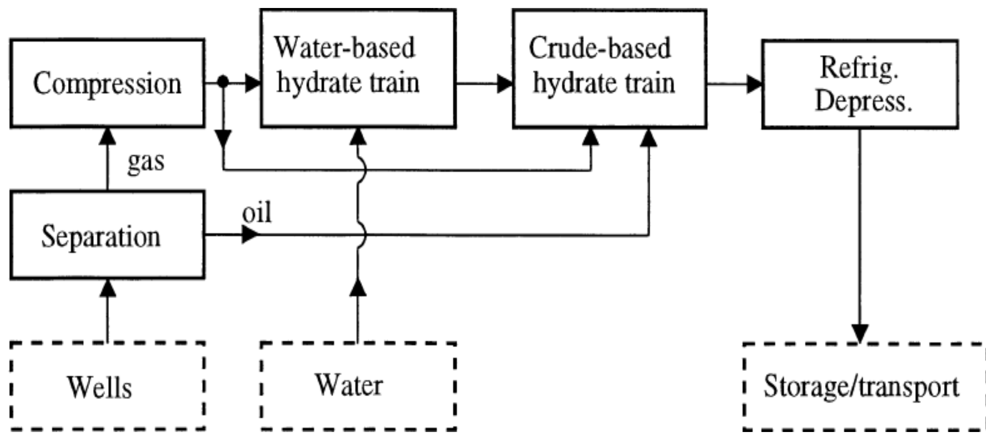

Figure 5. Simplified flow diagram of the hydrate slurry process.

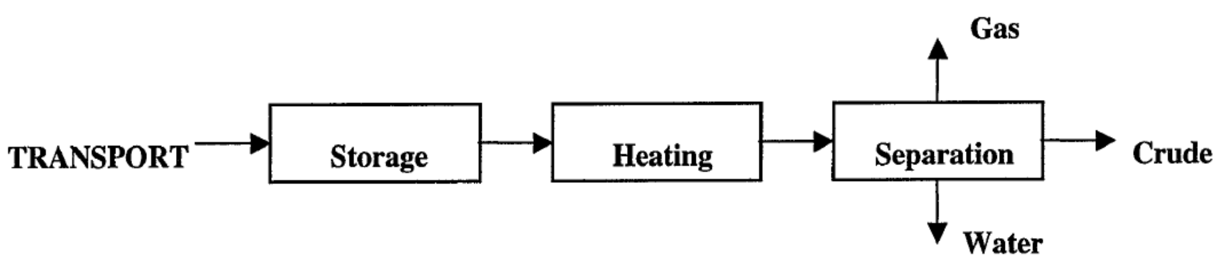

Figure 6. Block diagram for hydrate slurry separation.

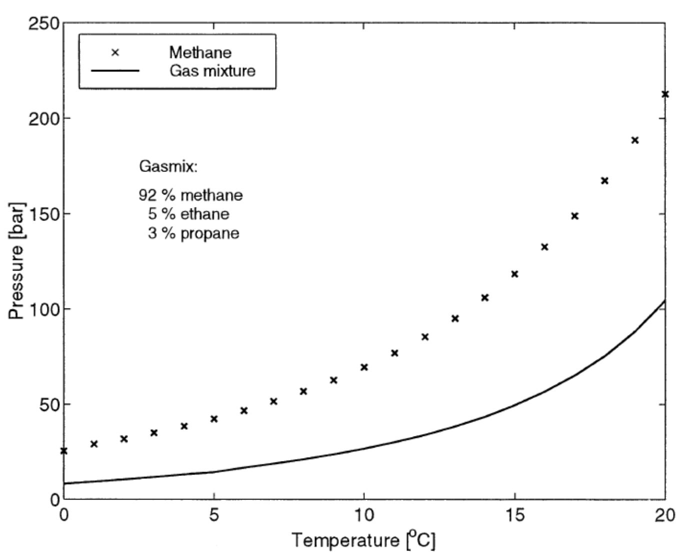

Figure 7. Hydrate equilibrium curves for methane and a gas mixture.

HOMOGENEOUS SLURRY FLOW IN PIPE

The transport of solid particles in liquids is identified as slurry flow. Slurry is homogeneous when the variation in the particle concentration is less than 20% from the bottom of the pipe to the top of the pipe (Crowe et al., 1998). Liquid-solid mixture with a small solid settling velocity may be treated as homogeneous slurry if the particles are homogeneously dispersed through the carrying liquid volume. As such, homogeneous slurries can be described by the equations governing single-phase fluids. As long as hydrates behave as homogeneous slurries, the concept of viscosity can be used to characterize the flow of hydrate slurries.

The theory for determination of the viscosity function assumes laminar flow conditions, and can therefore only be applied for pipe flow where the mean velocity is below that of the critical value. Extending the flow into the turbulent region, the concept of the hydraulic gradient is often convenient. Hydraulic gradient is the reduction in pressure head per unit length of pipe. Figure 8 illustrate hydraulic gradient curves where the hydraulic gradient is plotted versus the Reynolds number for pure liquid and for slurry flow. Here the slurry pressure gradient curve deviates from the liquid pressure gradient curve due to increased viscosity, and hence increased frictional pressure drop. Therefore, a shear thinning slurry is suggested for efficient flow in the pipeline. Solid agglomeration and pipeline blockage can be prevented

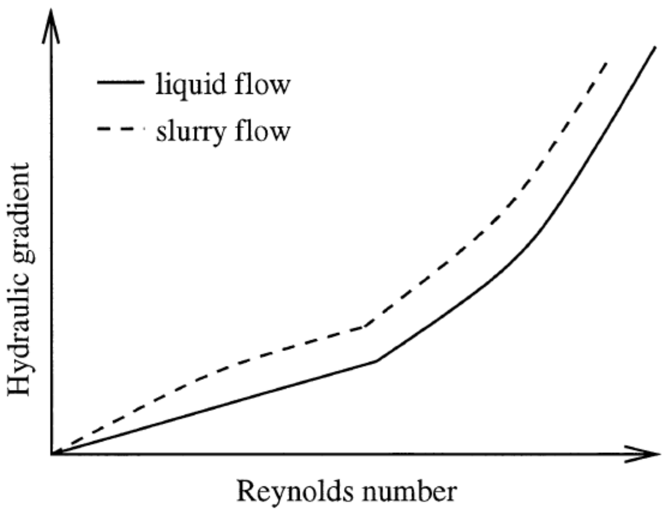

Figure 8. Hydraulic gradient curves for pure liquid low and for slurry flow.

by using low doses (few % by mass) of chemical anti-agglomerates, if necessary, thereby reducing the slurry viscosity.

TEMPERATURE CHALLENGES AND ECONOMICS

Hydrate formation are often associated with temperate region, where temperature conditions are most suitable for their formation, that is, low temperature. However, natural gas hydrate can also be formed at relatively high temperatures, even above 21°C (70°F) if pressure is high enough (Sivaraman, 2002). Therefore, with adequate temperature and pressure control, natural gas hydrate slurry can be produced and pumped through existing oil pipeline of the Niger Delta oil field; thereby reducing CAPEX/OPEX of oil field operations.

Compared to alternative technologies such as LNG and gas to liquids (GTL), NGH technology is relatively simple, low cost, and does not require complex processes or pressure and temperature extremes. Capital cost of NGH technology is approximately 25% lower than the capital cost of LNG technology (Masoudi and Tohidi, 2005).

CONCLUSION

The following conclusions can be drawn:

1. The natural gas hydrate process is a well-proven technology. The technology can be applied in remote areas where other gas exploitation methods are not economically viable (that is, stranded field) and where it is necessary to eliminate the high incidence of flaring gas during oil production.
2. Natural gas hydrate technology has the potential to convert a significant percentage of associated gases into hydrates at near source location. The process involves reacting gas and water in the presence of crude oil, operation at 10 to 15°C and 60 to 90 bar. The resulting hydrate slurry is stable at near atmospheric pressure and can be pumped through pipelines or transported by tankers to separators.
3. The simplicity and flexibility of the hydrate process makes the concept worth the development required. The processes do not involve extreme temperature, either high or low; do not require an oxidant or a catalyst, nor feature any complex unit operations other than standard process equipment.
4. In addition, the technology can cope with the intermittent and variable profile of gas production, as is usually the case with associated gas.

Conflict of Interest

The authors have not declared any conflict of interest.

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