Deepwater Technology for Oceanic Natural Gas Hydrate

Michael D. Max & Arthur H. Johnson
Hydrate Energy International, Inc.
Kenner LA, USA
m_max@hydrate-energy.com

Abstract—**Deepwater oceanic natural gas hydrate (NGH) is a potential unconventional natural gas resource. Since its recognition in the early 1970s, considerable research into its petroleum system, physical and chemical characteristics, and other attributes have been carried out. The resource is on the verge of being produced. Because oceanic NGH deposits occur within 1.2 km of the seafloor in semi-consolidated sediments world wide, and have very low environmental risk, it should be possible to develop a new range of 'lightweight' seafloor based technology that would have the effect of reducing the cost of both exploration and production dramatically.**

Keywords—unconventional; environment; drilling; natural gas hydrate; exploration: production

I. Natural Gas Hydrate

Natural gas hydrate (NGH) is a crystalline substance. It is a clathrate in which water molecules form cage structures that are occupied by gas molecules, the whole stabilized by the weak electrical force, van der Waals bonding. Biogenic methane is the dominant gas found in naturally occurring gas hydrates, although heavier density natural gases are common up to about 5-8% in structural situations such as sedimentary prisms above subduction zones where thermogenic gas may be generated at depth. Traces of other gases, such as H_2S, N_2, and CO_2, may also occur. The gas molecules are held close together in the crystal lattice, resulting in a compression factor of about 164 times by volume, at STP.

In brief, oceanic NGH is confined to deep continental shelf regions and continental slopes, with some practical depth limit defined by the physical chemistry of the system, which will not be discussed here, and operational water depths for exploration and recovery probably being no deeper than about 4km. NGH nucleates and grows when the concentration of the hydrate-forming gas in pore water within a pressure and temperature region of NGH stability is sufficiently high [1]. NGH forms over time from crystallizing solutions that may not contain free gas. It will only persist when the pore water in contact with it maintains a concentration of hydrate-forming gas. It is thus a living, rather than a fossil hydrocarbon deposit. This is a primary distinguishing characteristic and is unique in both conventional and unconventional hydrocarbons.

Concentrations of NGH may constitute an extremely large unconventional natural gas resource [2]. NGH occurs in two different environments on earth (Fig. 1), within permafrost mainly in Polar Regions but also at lower latitudes in high plateaus and mountainous terrains, but much more commonly in oceanic marine sediments on deep continental shelves and in continental slopes [3]. Oceanic and Permafrost NGH are fundamentally different. Permafrost NGH deposits on land can, in fact be modeled as would a conventional deposit.

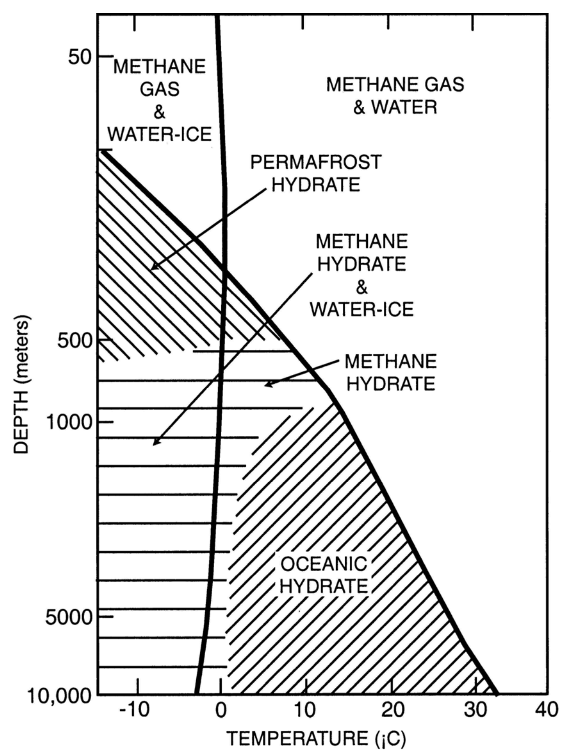

Figure 1. Phase diagram for methane hydrate showing permafrost and oceanic hydrate P-T regions. Solid line indicates approximate ice - water phase boundary. Original figure after [4].

Conventional exploration methods and especially drilling techniques will be used for permafrost NGH, although production methods will be different, especially if

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depressurization is used to convert the NGH to its constituent water and gas. Because our objective in this paper is to discuss new technology that may be used for oceanic NGH exploration and development, these will not be discussed further here.

The geographical and geological setting of oceanic NGH, and its mode of occurrence is very different from conventional hydrocarbon deposits and may be new to those having considerable hydrocarbon energy expertise. We contend, however, that those differences, once understood, provide the rationale for reassessing existing exploration and production methods.

In contrast to the structurally strong conventional gas deposits, NGH forms in thermodynamic traps within the GHSZ. That is, although NGH concentrations may occur within porous and permeable beds capable of supporting pore zone transport from deep gas sources to the seafloor that may be bounded by less permeable and geotechnically stronger strata, there generally is no physical trap that would act to restrict the flow of gas away from a converted NGH concentration. It is the NGH itself, which is the gas trap.

NGH is presently the subject of exploration and development as a potential economic natural gas resource. Japan, China, India, and Korea have very active programs and many other nations are carrying out low-level exploratory NGH potential assessments and are considering establishing NGH programs. There is little doubt that the results of tests bearing on commercialization of NGH are being closely monitored by both governments and private companies. With the abundant and growing supply of oil and gas from shales and tight sand, the United States NGH research program is now refocusing from energy to other aspects of ocean and environmental studies. However, coastal states without these hydrocarbon riches have maintained active NGH research program focused on energy.

Japan is currently leading NGH development, and since 1995 has maintained a focused, well-funded program. This program marked a milestone in March 2013 when a 5.5 day technical production test of the Nankai NGH deposit about 60 km to the SE of Tokyo Bay was successfully carried out. JOGMEC, the Japanese operator, has restated the aim of the second phase of the Japanese NGH program that is to continually produce natural gas for their home market by 2018.

II Natural Gas Hydrate Economic Parameters

NGH is only found within the gas hydrate stability zone (GHSZ). Understanding the position of the GHSZ (Fig. 2) and the material in which it forms is probably the most important factor governing its geographical and physical parameters. NGH is most stable in marine sediments immediately at the seafloor, where temperatures are cold, usually less than 4 ^{o}C except in Polar Regions where seafloor water can be below 0 ^{o}C. Even in restricted seas such as the Mediterranean in which seafloor temperatures are in the vicinity of 15 ^{o}C because the deep cold water from the Polar Regions does not flow into it, the general thermodynamic system for the GHSZ remains the same. NGH in the GHSZ is most stable at its seafloor top and gradually becomes less stable with increasing depth, until at some depth the base of the GHSZ, which is determined by increasing temperature, the NGH is no longer stable. NGH is less stable with depth as the temperature rises due to geothermal gradients and heat conducted from below. The base of the GHSZ marks a metastable zone below which free gas and water may occur.

There is a happy coincidence between the base of the GHSZ being most heavily mineralized with NGH and the nearness of the NGH to the base of its stability field. The 'closer' to the edge of its pressure-temperature stability field a NGH deposit is, the lower the lower the energy input required for any method of converting it to its constituent gas and water.

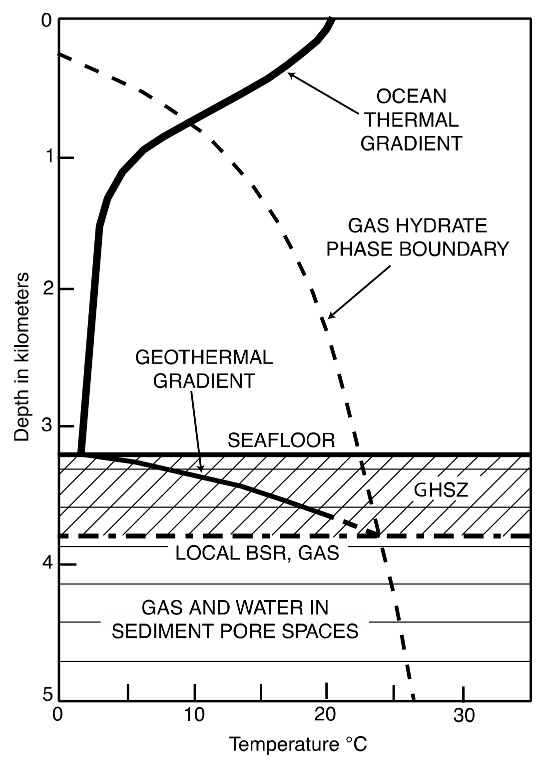

Figure 2. Oceanic GHSZ as a function of typical open ocean thermal gradient and geothermal gradients. Original figures after [4] and [2].

Although NGH is has been found virtually throughout the GHSZ, economic targets are likely to be concentrated near its base. The position of the largest NGH concentrations at and immediately above the base of the GHSZ has been shown by drilling in the northern Gulf of Mexico [5], [6], [7] and in the Nankai deposits off Japan [8], [9]. The location of the largest concentrations of NGH near the base of GHSZs is a positive factor for both exploration drilling and production. Where the sediment has been most deeply buried, it will be more compacted under the influence of gravity than in more shallowly buried sediments at the base of a thinner GHSZ.

The level of compaction of the NGH host sediments and particularly the degree of compaction and reduced permeability of sediments bounding a sand-hosted NGH deposit may strongly control the percentage of technically and economically recoverable natural gas. NGH will generally occur world-wide in semi-compacted sediments that do not have the geologically strong character of conventional natural gas reservoirs. The stronger the geomechanical character of the reservoir sediments and between the NGH deposit and the seafloor, the lower the risk of mechanical failure and more likely higher rates of NGH conversion [10] and natural gas production.

Potentially economic NGH concentrations will only be found in a GHSZ thick enough to host a thick enough pay zone, and with enough overlying sediment to physically stabilize the reservoir when gas is produced during NGH conversion, and gas extraction. In some cases, the presence of multiple NGH-enriched units [1] multiple payzones may occur, each with a different set of geotechnical parameters. NGH-enriched sediment can be mechanically very strong when NGH concentrations are high and they will weaken as NGH is converted and produced. The thickness and strength of a GHSZ necessary to host a producing NGH deposit is not known.

In summary, NGH reservoir conditions are likely to be similar worldwide. Deposits will likely occur in semi-consolidated sandy sediment within the near seafloor GHSZ (< 1.2 km below seafloor).

III NGH Exploration and Production Factors

NGH is a unique natural gas resource. Constraints on its exploration and production largely arising from the relative weakness of the reservoir and its surroundings, however, may be less important than cost reductions and increases in safety that may be achieved by 'leveraging' or responding innovatively to NGH and its reservoir parameters. In other words, what to conventional eyes may appear to be negative factors may actually allow the development and implementation of new technologies that have considerable potential for decreasing cost while increasing safety.

Because NGH will occur in approximately the same materials within a restricted distance from the seafloor, only a limited drilling capability is required. In addition to the time saving of only needing to drill shallow wells, each of which will take a short time compared with a normal much deeper conventional well, lighter duty drilling apparatus can be used. However, it is likely that wells deeper than 1.2 km may be unnecessary for NGH, but longer low angle wells are very likely so that total drilling time on station may be required.

Possibly the greatest contrast between conventional gas deposits and NGH is that the NGH is stable at ambient reservoir conditions. That is, its temperature is low, and unlikely to be greater than 40 ^{o}C, even in the deepest water, thickest GHSZ deposits, and it pressure will be the ambient formation pressure. In addition, the NGH is usually almost pure methane. Thus, the higher temperatures and condensates and chemicals often associated with conventional deposits are absent. Further, because pressure differentials within the seafloor will be low, and gas volumes and pressures can be controlled, production measures can be undertaken that are not practicable for conventional natural gas deposits.

So long as the conditions of temperature and stability of NGH reservoirs are maintained, no free gas will be generated from the NGH. With proper NGH practices, wells cannot get out of control and there is virtually no danger of blowout. Because the presence of gas is due to the artificial application of one of a number of what would be regarded as secondary recovery techniques within conventional hydrocarbon drilling and production, the simple cessation of those activities will end the conversion of NGH to gas. Further, once conditions of NGH stability are restored, free gas will tend to reform NGH naturally, and this process can be further accelerated if desired.

The NGH resource is poised for commercialization. Exploration methods have been confirmed [6], [7] and the first production test has been accomplished. Although shale gas currently is inhibiting NGH development around North America, the gas glut in US is unlikely to stop NGH development elsewhere, especially in those places where lack of foreign currency is more important than energy as a national security issue. Indigenous energy competes directly against high cost imports. More important, the cost of NGH development will be brought down as as new and improved technology and approaches are developed for NGH, as has been the experience with other natural resources.

IV The Environmental Factor

NGH within the reservoir is at formation pressures and thus cannot blow out. Gas trapped in permeable beds below the level of the GHSZ is not at high pressures and is also at the formation temperature for a slightly greater depth. Production factors are also benign. If depressurization is used as a conversion method [10], for instance, the free gas pressure can be kept below the formation pressure for the duration of gas production. This is the antithesis of a high-pressure gas deposit that could blow out if improperly managed. If the pressure differential produced by production causes some sort of mild 'implosion' the conversion in process can be aborted instantly, and the gas will tend rapidly to reform NGH rather than blow out.

There are rarely associated natural gas liquids (except where compound hydrate formed from more than one hydrocarbon gas) and petroleum is virtually unknown in association with NGH. Thus, even if there were a minor breach of the reservoir, either natural or caused by the drilling or production activity, there would be no appreciable negative impact upon marine life and the environment in general.

Thus there is a low environmental risk associated with NGH. We regard this factor, which has apparently been overlooked by both industry and regulatory authorities to date, as a very positive factor and one that may prove critical to NGH production, particularly in environmentally fragile areas such as the Arctic Ocean.

V How Can New Technology Provide a Decisive Margin for NGH

Among the keys to our technology development for deepwater NGH-specific technology were the results of the JIP program of the U.S. Department of Energy and BOEM (old MMS) in producing workstation software capable of identifying, categorizing, and 'valuing' NGH concentrations on a cell basis (similar to conventional mineral deposits), which were then confirmed by drilling [6], [7], [8]. We considered this the 'ready to go' moment. With convincing and successful remote exploration seismic data available, the next step must be to review the technology and methodology for NGH exploration and production. Another key was a reevaluation of NGH potential in the Arctic Ocean [11], in which we were able to review the broad range of deepwater developments in conventional hydrocarbon exploration and production.

The cost of NGH development is currently modeled as the cost of conventional development plus the cost of converting NGH to its constituent gas and water, plus the costs of flow assurance and other factors. Most of the cost projections for NGH do not involve the application of any truly innovative new technology or approaches. We have never seen a true comparison between the costs of conventional deepwater gas and NGH because unconventional development is never introduced as a factor.

We propose that there are a number of technical fields, particularly in drilling and preparing a deposit for production, as well as some new production methodology, that offer considerable scope. Although we have counseled in our publications over the years that the particular attributes of NGH and the sediment within which it occurs would allow development of new methodologies and technologies that could have dramatic impact upon commercialization of the potential NGH resource.

In the first instance, lighter duty vessels from which drilling operations can be carried out or controlled may be used, in contrast to the heavy drilling capability currently in practice. To some extent this movement to lighter and less expensive vessels has been underway for some time, along with the application of coiled tubing for at least well maintenance, if not the primary drilling capability. However, lighter drilling tools and support apparatus offer considerable scope for innovation. Lightweight drilling capability is particularly appropriate for the shallow NGH drilling targets.

The core of our NGH specific technology is that everything, especially drilling or the NGH equivalent, can be moved to the seafloor. Processing equipment, for instance gas-water separators, pumps, and well control apparatus has already begun a migration to the deepwater seafloor. Both rotary and coiled tube drilling from the seafloor are possible. We propose that because of the generally benign nature of NGH-enriched strata, modest overpressure drilling can be done through pressure lock BOPs that will be adequate to insure drilling and reservoir safety.

Drilling will follow a possibly higher level of shallow hazard studies that will allow avoidance of gas pockets and other suspiceous zones. Because of the low NGH reservoir pressure differential with the seafloor, it is simply unnecessary to have substantial drilling mud in a riser as there is no need to hold high pressure conventional gas in its reservoir. Light pumps or other methods can maintain pressure.

It may well be that a mixed NGH-free gas zone will occupy a relatively wide metastable zone at the base of the GHSZ, which is up to 80 m thick at Blake Ridge and a sub-GHSZ free gas zone up to 300 m thick [12] will be found in association with potentially commercial NGH concentrations. In this case, artificially induced well pressure will have to counter positive gas pressure. Trapped gas in closed system permafrost NGH traps are not much higher than hydrostatic [13]. There is little data relating to gas pressure at and below GHSZs in hydraulicly open oceanic NGH systems as drilling has avoided them. It would appear that the trapped gas pressure is not high as high pressure would cause local pull-down in the base of the GHSZ, which has not been observed. Pressures of gas trapped below oceanic NGH are probably no greater than 2% above hydrostatic [14].

Carrying out drilling operations directly from the sea floor means that in weather and climate restricted areas such as the Arctic Ocean, largely weather independent operations can be carried out. Resupply can be made by submersible supply vessels, building on Navy technology and experience. A number of scenarios are currently being developed to deal with the issue of stranded (conventional) gas and all will apply directly to natural gas produced from remote NGH deposits. Just as much of the technology that needed development for the NGH deepwater has been developed for conventional hydrocarbons, NGH will piggyback on these developments without having to invest separately.

Being able to drill wells in developing a NGH deposit for production under relatively low-pressure differential and non-hazardous chemical conditions allows considerable new equipment in well bores. For instance, visibility within the well bore may be great enough to allow submersible cameras to be used during operations to allow for manual control of downhole apparatus that may be used.

Because drilling will take place in semi-consolidated sediments and NGH enriched zones, we envisage that a range of considerably improved bottom hole apparatus (BHA) based loosely on those currently used for coiled tubing drilling and for tunneling in soft sediments can be developed. We envisage that these will be larger and more maneuverable within the wells, which themselves will be larger. We also envisage that these advanced BHAs will have AUV capabilities and the potential to operate mission specific ROVs within the well.

We envisage that with this approach, much more complex variable orientation wells can be driven. We also envisage that because the pressure differential between the well bore and the formation, and the seafloor, for that matter, well liners will not have to be of strong steel or other metal. Scope exists for well liners to be formed in a number of other methods that are described in proprietary reports that we have authored.

A robotic approach will be optimized throughout. Although robotics are already being applied to virtually all technology and business fields, the manner in which seafloor apparatus, down-hole apparatus, and the exploration and preparation drilling communicate and cooperate will involve new applications to the field.

A new range of semi-autonomous service vehicles / apparatus operating in a manual override autonomous manner will service the seafloor operation. Again, these general developments are already taking place for supporting conventional drilling operations carried out from sea surface platforms, but because of the greater degree of autonomy and flexibility of downhole equipment, there is considerable potential for innovation.

We envisage that very long pay sections of gas removal wells may be paired with crossflow wells to manage primary gas and water management and separation in the reservoir itself. NGH specific well layouts will look considerably different from even the current single drilling pad - multiple hole developments.

VI Conclusions

Seafloor drilling operations are feasible for NGH.

The technology required for seafloor NGH developments can be achieved from the existing industrial base.

Because of the relatively benign pressure, temperatures, and chemical characteristics of a potential NGH deposit, considerably different and potentially less expensive methods can be developed and employed than have to be used for conventional gas deposits.

Lower materials requirements and lower operational costs should be obtainable through new technology development.

NGH specific technology development may have some application in non-NGH deepwater spinoff.

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