NATURAL GAS HYDRATES in INDIA

Prof. Y. F. Makogon,
Texas A&M University

Abstract

Natural Gas-Hydrates is untraditional mineral energy, when natural gas exist in the reservoir in solid state (Makogon, 1965). All hydrocarbon gases form hydrates. One m³ of hydrate consist 164 m³ of methane. Gas hydrates form and exist in reservoir under high pressure and low temperature. About 97% of hydrated deposits exist in offshore. Present time recovered over 200 gas-hydrate deposits (GHD) in offshore. A map of the discovered GHD is shown in Fig. 1.

World potential resource of hydrated gas is over 1.5*10¹⁶ m³ (Makogon, 1982). Commercial production of just 15% of this gas will provide the world with energy for 200 years at the current level of the energy consumption. Development of gas-hydrate deposits can be done by reduction pressure, by increasing temperature or injection different inhibitors (Makogon, 1966). Present time we can use new progressive technology). The production of natural gas from hydrates could be used to contribute not only to the sustained economic development of the individual countries, but also to the political stability in the world.

We have good results of long commercial production of hydrated gas in Siberia. Same time, many complicate problems need be study. We need high level of experts for study gas hydrate properties and use new production technology of hydrated gas. Gas hydrate resource distributed convenient for development by most of country. Necessary remember that for us important not value of potential resource of hydrated gas, but volume of gas what can commercially produce (17-20% from potential).

First Indian federal program for research and development GHD was started in February 1996 by ONGC. According this program in India was established new laboratory and departments with high qualification experts, it was good connection with industry, where exist serious experience for gas production in offshore conditions. Geology situation in offshore of India is one of the best in the world for recovery GHD. As results of cooperative work last year was drilled more than 30 wells for recovery GHD. Best results was in Krishna-Godavari region, where was
received good resource of hydrated gas – $8 \times 10^9 \text{ m}^3/\text{km}^2$. This results demands more work. India can be first country, where will be successful production of hydrated gas in offshore. 

**Keywords:** natural gas-hydrates; zone hydrate formation; development;

**Introduction**

The history of humanity is characterized by competition for the living space on our small planet. The past century has been one of high population and energy consumption growth. Over the past one hundred years, the population on Earth grew four-fold, exceeding 6.3 billion, while the energy consumption grew by over an order of magnitude, from $0.9 \times 10^9$ tons of oil equivalent (1900 Y) (toe) to $10.88 \times 10^9$ toe, (BP SRWE, 2007).

The rate of modern civilization growth in the future will depend on numerous factors, but the quality and quantity of energy used will be one of the most important factors. The data presented in **Fig. 2** reflect the distribution and changes of energy sources in time. From Table 1 we can see real situation with consumption of primary energy in the world and some country, include India.

**Table 1. World energy consumption, $10^6$ t.o.e./2006**

<table>
<thead>
<tr>
<th>Country</th>
<th>Total.En.Cons</th>
<th>%</th>
<th>Population.</th>
<th>%</th>
<th>t.o.e./capita</th>
<th>times/US*</th>
</tr>
</thead>
<tbody>
<tr>
<td>World</td>
<td>10879</td>
<td>100</td>
<td>6600</td>
<td>1.65</td>
<td>1.65</td>
<td>4.7</td>
</tr>
<tr>
<td>USA</td>
<td>2326</td>
<td>21.4</td>
<td>300</td>
<td>4.5</td>
<td>7.75</td>
<td>1</td>
</tr>
<tr>
<td>Russia</td>
<td>705</td>
<td>6.5</td>
<td>140</td>
<td>2.1</td>
<td>5</td>
<td>1.5</td>
</tr>
<tr>
<td>S.Korea</td>
<td>226</td>
<td>2.1</td>
<td>48.4</td>
<td>0.7</td>
<td>4.7</td>
<td>1.7</td>
</tr>
<tr>
<td>Japan</td>
<td>520</td>
<td>4.8</td>
<td>127.4</td>
<td>1.9</td>
<td>4.1</td>
<td>1.9</td>
</tr>
<tr>
<td>China</td>
<td>1698</td>
<td>15.6</td>
<td>1306</td>
<td>20</td>
<td>1.3</td>
<td>6</td>
</tr>
<tr>
<td>India</td>
<td>423</td>
<td>3.9</td>
<td>1100</td>
<td>16.6</td>
<td>0.38</td>
<td>21</td>
</tr>
</tbody>
</table>

* - What is difference with USA consumption

From Table 1 we can see that India needs much more energy for grow industry and improve life level of population. Consumption of primary energy in India (t.o.e./capita) less than world consumption in 4.3 and 21 times less than in the USA. Same time India has huge resource of coal on the land and hydrated gas in offshore.

Usually gas-hydrate layers exist from 50-200 m to 300-500m depth from the sea floor.

Four years ago I published map (**Fig. 3**) with different prospects for express seismic and recovery work dependence on four factors: water depth; thickness of sediment; concentration of organic in the sediment; sea floor temperature and geothermal gradient. According this map most
perspective region for recovery gas-hydrate fields is Krishna-Godavari region. Last year in Indian offshore was drilled over 30 recovery wells with coring and geophysics of wells what supported that recommendations. In the western offshore of India and Andaman region hydrate also has perspective, however necessary more geology data and primary digital seismic work before drilling recovery wells.

From Fig. 4 we can see primary results of testing one of the well in Krishna-Godavari region. According this picture we can primary calculate potential resource of hydrated gas, what exist in sediment on the depth 1080-1205 m. It is difficult predict total resource in this region, however, around this well potential resource of hydrated gas is about $8 \times 10^9$ m$^3$/km$^2$.

To rapidly improve the technology, the industry should form an International Coordination Board to help solve the vital problems associated with the development of GHDs. The board should provide guidance to get research money to the right organizations for the right projects. The world will eventually need the energy concentrated in natural gas-hydrates. However, the technology must be developed now to be able to produce GHDs in the coming 10-15 years.

**The brief characteristic of gas-hydrates**

Gas-hydrates are compounds, in which the molecules of gas are occluded in crystalline cells, consisting of water molecules retained by the energy of hydrogen bonds. Gas-hydrates can be stable over a wide range of pressures and temperatures. For example, for methane from 20 nPa to 2 GPa at temperatures from 70 to 350 K. The morphology of hydrate crystals is very diverse and is determined by composition and conditions of crystal growth.

Some properties of hydrates are unique. For example, 1 m$^3$ of water may tie up 207 m$^3$ of methane to form 1.26 m$^3$ of solid hydrate, while without gas 1 m$^3$ of water freezes to form 1.09 m$^3$ of ice. One volume of methane hydrate at 26 atm and 0°C contains 164 volumes of gas. In hydrate, 80% of volume is occupied by water and 20% by gas. Thus, 164 m$^3$ of gas are contained in a volume of 0.2 m$^3$. The dissociation of hydrate by increasing temperature when the volume is held constant will be accompanied by a substantial increase in pressure. For methane hydrate formed at 26 bar and a 0°C, it is possible to obtain up to 1600 bar pressure increase. Hydrate density depends on its composition, pressure and temperature. Depending on the composition of gas, pressure and temperature the density of the hydrate will vary from 0.8 to 1.2 g./cm$^3$. 

Natural gas-hydrates are metastable minerals, where the formation and/or decomposition depends on pressure and temperature, composition of gas, salinity of he water, and the characteristic of the porous medium in which they are formed. Hydrate crystals in reservoir rock can be dispersed in the pore space without the destruction of pores, but in some cases, the rock will be affected. Hydrates can be in the form of small nodules (5-12 cm) or in the form of the small lenses or even in the form of pure layers that can be several meters thick.

To liberate gas from a GHD, one has to heat up the entire rock mass containing the gas hydrate. The amount of energy needed will depend on the heat capacity of the hydrate, the heat capacity of the hydrate saturated layers, the specific amount of hydrate in the layers and the degree of supercooling caused the formation of the deposit. Under certain conditions, the energy necessary for liberating the gas in the hydrate layer, can exceed the value of potential energy of gas that will be produced. Hydrates possess high acoustic conductivity and low electrical conductivity, which is used for the effective methods of finding and evaluating a GHD. The decomposition of hydrate in the layer, especially under the conditions of ocean areas, can be accompanied by the significant changed in the strength of the sediments containing the gas hydrates. The experimentally specific values of the heat of the formation - decomposition of hydrates of the separate hydrocarbons in the temperature range of the melting of water are given below (Handa, 1986)

<table>
<thead>
<tr>
<th></th>
<th>T&lt; 273 K</th>
<th>T &gt; 273 K</th>
</tr>
</thead>
<tbody>
<tr>
<td>CH4</td>
<td>18.1 ±0.3 kJ/mole</td>
<td>54.2 ±0.3 kJ/mole</td>
</tr>
<tr>
<td>C2H6</td>
<td>25.7 ±0.3 kJ/mole</td>
<td>71.8 ±0.4 kJ/mole</td>
</tr>
<tr>
<td>C3H8</td>
<td>27.7 ±0.3 kJ/mole</td>
<td>129.2±0.4 kJ/mole</td>
</tr>
<tr>
<td>i-C4H10</td>
<td>31.0 ±0.2 kJ/mole</td>
<td>133.2±0.3 kJ/mole</td>
</tr>
</tbody>
</table>

The Location of Gas Hydrate Zones
The mechanism of how gas-hydrate deposits are formed and where hydrates are located their location has been affected by numerous factors, such as (1) thermodynamic regime in the region; (2) the intensity of generation and migration of hydrocarbons; (3) the composition of the gas; (4) the degree of gas saturation and salinity of the reservoir water; (5) the structure of the porous medium; (6) the lithologic characteristics of section; (7) the geothermal gradients in the zone of hydrate formation and in the basement rocks; and (8) by the phase state of hydrate formers.
The Hydrate Formation Zone (HFZ) represents the thickness of sediments in which the pressure and the temperature correspond to the thermodynamic conditions of stable existence of hydrate of gas of a specified composition. These HFZs are found where the earth is cool, such as the arctic and deep water. With an increase in the salinity of water, the thickness of the HFZ decreases. The thickness and the temperature of the HFZ in the offshore strongly depends on the value of sea bottom temperatures, gradient in the sediments. With an increase in sea bottom temperatures, the size of the HFZ decreases. In the regions where permafrost exist, the thickness of sediment in which gas-hydrate deposits exist can reach 400-800m. The HFZ in the ocean is found in the deep water shelf and the oceanic slope with the depths of water from 200 m or deeper for the conditions of in northerly oceans, and from 500-700 m or deeper for the equatorial regions. The upper boundary of the HFZ offshore is located near the sea floor.

**Characteristic of gas-hydrate deposits (GHD)**

There are two basic forms of GHD: primary and second. A primary deposit is one that formed and has never melted. Primary deposits are usually found in deep water, where temperatures do not change rapidly overtime.

Primary deposits are formed by the gases dissolved in the reservoir water and are located in the near sea-floor sediments, which are characterized by high porosity, low temperature and low rock strength. Frequently, a primary GHD does not have good barriers or seals. The hydrate begins formers in the pore space and eventually plugs the migration paths which traps more hydrate. The hydrate can also be the cement holding the rock together. After the decomposition of hydrate, the porous media may revert back to an unconsolidated formation.

Gas-hydrate in primary GHD can be found in the dispersed state or in the form of nodules. For a primary GHD, the gas can be found over large areas that do not depend on geology structures. We can also find free oil or gas under primary GHD. Secondary GHD are usually located in the Arctic onshore. They are formed from the deposits of free gas, located under the impenetrable formation layers (traps) with a temperature decrease in the formation that is lower than the equilibrium temperature for the gas of this composition. The temperature in the rock layers on the continents will cycle repeatedly in geologic time. During these cycles, the gas hydrates in the rocks will form and dissolve as the temperature cycles. Many times, there will be free gas or oil under the hydrate layers.
The most promising regions to look for commercial deposits of gas-hydrate are the deep water shelves, continental slopes and continental abyssal trenches, with the depths of water from 700 m to 2500 m. The most promising resources of gas-hydrate are concentrated in only 9-12 % of the ocean floor.

There is a lot of rock where the pressure and temperature are favorable for the formation of gas hydrates. However, in most of the rock, the saturation of gas hydrate will be too low to be commercially developed. For example, on Messoyakha only 40 m of hydrate has been identified in the HFZ layers that are 600 m thick. This corresponds to 6.6% of thickness of the HFZ. In the Nankai Trough offshore Japan, there are 505 m of overall thickness of the sedimentary rocks, in which thermodynamic conditions correspond to formation and stable existence GHD. However, only 17 meters contains gas hydrates at reasonable saturations, which is only 3.4% of the total thickness. At Blake Ridge, located on the East Cost of the USA, the hydrate formation zone is 440 m thick. However, only 7.5 m, which composes only 1,7% of the thickness HFZ contains hydrate.

To rapidly improve the technology, the industry should form an International Coordination Board to help solve the vital problems associated with the development of GHDs. The board should provide guidance to get research money to the right organizations for the right projects. The world will eventually need the energy concentrated in natural gas-hydrates. However, the technology must be developed now to be able to produce GHD in the coming 10-15 years.

**The methods required to develop GHD**

The following properties are used when we devise ways to evaluate GHD: (1) high acoustic conductivity, (2) high electrical resistance, (3) lowered density, (4) low thermal conductivity, and (5) low permeability for the gas and the water. We can evaluate GHD by using seismic data, gravimetry, measurement of heat and diffusion fluxes above the GHD, and measurement of the dynamics of electromagnetic field in the region being investigated. The most common method is seismic surveying at frequencies of approximately 30-120 hertz with the resolution to 12-24 m and high-frequency. We can use standard 2-D seismic to locate the lower boundary of the hydrate saturated formation by looking for a bottom seismic reflector (BSR). BSR are caused by free gas underneath the hydrate layer. Unfortunately, 2-D seismic surveying does not answer
many most important questions, in particular, it does not give the data about the degree of hydrate-saturation of layers.

The results of 3-D seismic surveying of high resolution are more informative and make it possible to determine lower and upper boundaries of the hydrate-saturated layers. We may also soon learn how to evaluate the concentration of hydrate in the rock layer, which makes it possible to determine the amount of gas trapped in GHD. Detailed evaluation of GHD is accomplished by combining seismic with well log and core data obtained from wells. However, much more research is required to perfect new methods, and improve interpretation of standard seismic data.

**How can we eventually produce gas from a GHD?**

To eventually produce gas economically from GHD, it is important to determine not the potential gas-in-place in GHD, but what amount can be extracted economically. The effectiveness of the extracted resources is determined by geological and thermodynamic conditions, and also by specific concentration of gas-hydrate in the deposit. To produce the free gas, the GHD must be changed from a solid to a fluid.

Thus, it is necessary to use much of the energy contained in the GHD to heating the GHD and the rock layers near the GHD. Primary calculation show that the coefficient of the extraction of the hydrated gas can reach 50-70%, however, from total world potential resource it should average from 17 to 20 %.

For offshore conditions, with the depths of water from 0.7 to 2 km effective production of gas from GHD in the majority of the cases may occur when hydrate saturation of porous media is more than 30-40%. However, each geologic region will have to be studied in details to know the minimal hydrate saturation that will be required. To change GHD to natural gas, it is necessary to (1) decrease reservoir pressure lower than equilibrium, or (2) increase the temperature higher than equilibrium or (3) the inject active reagents, which facilitate the decomposition of hydrate. The easiest method is to lower the reservoir pressure in GHD, this method is only feasible when free gas is found below the GHD.

**Fig. 5** shows the P-T conditions of some real GHD, located offshore (Makogon, etc. 2004).
It is clear that the majority of the GHD are in the supercooled state, i.e., the temperature of the hydrate saturated layers is stratified considerably lower than equilibrium. In this case, the pressure in GHD should exceed equilibrium by more than several tens atmosphere, (For offshore regions it can’t be done) and strongly increase reservoir temperature, Fig. 6.

About effective technology for development gas-hydrate deposits in Indian offshore situation see next our paper, or contact author.

**Conclusion**

We will not run out of fossil fuels in the 21st Century. Energy, concentrated in natural gas-hydrates including India can possibly be an energy source for the majority of the 21st Century. Natural gas-hydrates are more evenly distributed on the planet than other sources of oil and gas. The production of gas from GHD will accessible to many countries. Many existing technologies can be used to find and develop GHD. However, significant Research and Development will be necessary before GHD can be developed economically.

The economic and ecological aspects of producing a GHD must be computed. Both the economics and the ecological aspects depend upon of the geology situation and utilized technologies.

The economics of producing GHD are not well understood because there are too many unknowns. In addition, each GHD will be different so different technologies may have to be employed. Experience in Messoyakha field showed that the cost required to produce the GHD was about 15-20% higher than a conventional gas field in the same area.

Commercial development of an offshore GHD will be more expensive than a conventional field. Expenditures for drilling GHD are considerably smaller than to drilling of gas or natural gas deposits, because GHD will be shallow. To improve development economics of GHD, better formation evaluation technologies will be needed to better define the GHD.

The most important question is the creation of the highly effective technologies of the transfer of gas from the solid into the free state directly in the layers.

Studies of natural gas-hydrates must be coordinated on a world scale, which could speed up technology development.
Reference:
BP Statistical Review of World Energy, 2005
Cook Ann, Preliminary Results from: National Gas Hydrate Program - India Science Party NGHP-1 October 5, 2006
Makogon Y.F. Peculiarities a Gas-Field development in Permafrost. Nedra, Moscow,1966
Makogon Y.F. Natural Gases in the Ocean and the Problems of Their Hydrates. Moscow, VNIIAGasprom. Express-Information, No.11, 1972
Makogon Y.F. Hydrate of Natural Gas (237 pg.) Nedra, Moscow, 1974
PennWell, Tulsa, 1981
Makogon Y.F., Hydrates of Hydrocarbons (1997) Penn Well, Tulsa, USA
Makogon Y.F., Holditch S.A., Makogon T.Y. Proven Reserves and Basics for Development of Gas Hydrate Deposits, AAPG, Vancouver, 2004

Contact: makogon@tamu.edu
Fig. 1 Map of discovered Gas-Hydrate Deposits

Fig. 2 World Energy Balans
Fig. 3 Different level of perspective regions for recovery GHD in India

Fig. 4 Gas-Hydrate saturation, K-G region (Cook Ann, 2006)
Fig. 5 Equilibrium P-T Hydrate dissociation in free space with sea water

Fig. 6 Geothermal conditions of GHD... for development