**Review of****exploration and production technology of**

**natural gas hydrate**

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**Abstract:** Natural gas hydrate (NGH) is a kind of clean and non-renewable energy source with huge levels of existing reserves, and its production value has attracted more and more attention. However, NGH production is still in the stage of conceptual and experimental research. In this paper, the main exploration methods such as geophysical exploration and geochemical exploration are introduced, the main production methods of natural gas hydrate are summarized in detail, including pressure reduction, thermal stimulation and chemical injection. Finally, the challenges and prospects of gas hydrate production are put forward.

**Keywords:** gas hydrate; exploration methods; production methods

1. **Introduction**

Natural gas hydrate (NGH) is a kind of clean and non-renewable energy source with huge levels of existing reserves, and its production value has attracted more and

more attention. NGH deposits are different from traditional energy deposits in terms of the production phase and the energy utilization form (Demirbas, 2010; Moridis et al., 2011). For coal, oil and natural gas, their own energy is used after being produced from the underground. For natural gas hydrates, however, they are in the solid state underground, and they dissociate into natural gas and water aboveground; thus, only the energy of the natural gas can be used (Deng, 2015). Up to now, however, NGH production is still in the stage of conceptual and experimental research, and there is not a complete set of NGH production principles available. To realize its commercial application, there is still a long way to go (Moridis et al., 2007, 2011; Demirbas, 2010).

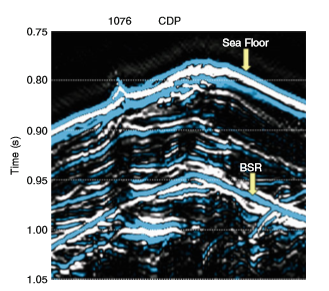
In this paper, the current exploration and production metheds of NGH are reviewed. The development of innovative NGH production technologies are presented in detail. Finally, the challenges and prospects of gas hydrate production are put forward, thereby providing future reference for the development of NGH production in China.

1. **Exploration Methods**

**2.1 Geophysical Exploration**

As an important future energy, NGH’s exploration is of great signiﬁcance (Moridis et al., 2007; Lee et al., 2011). Gas hydrate deposits are identiﬁed principally on the basis of their acoustic expression. The phase boundary between methane hydrate and methane plus water gives rise to a prominent negative-polarity event known as a BSR. Besides, the addition of hydrate to pore ﬂuids has been interpreted to cause acoustic blanking, a suppression of sediment reﬂectivity. Fig. 1 is a classic example of identiﬁed BSR.

Fig. 1 A classic example of identified BSR (After Thakur, 2010)



Previous studies suggest that most of the BSR amplitude is due to the velocity reduction of the underlying free gas (Singh et al., 1993). The presence of a free-gas zone (FGZ) is an important part of the gas hydrate system, and is particularly important if the presence of gas hydrate is to be inferred by observation of a BSR(Haacke et al., 2007). Both methane hydrate and free gas exist even where a clear BSR is absent. The low reﬂectance, or blanking, above the BSR is caused by lithologic homogeneity of the sediments rather than by hydrate cementation. The average methane hydrate saturation above the BSR is relatively low (5 to 7 percent of porosity) (Holbrook et al., 1996).

* 1. **Geochemical Exploration**

Geochemical exploration is performed by analyzing actual core samples. However, geochemical exploration serves an important role in gas hydrate exploration combined with geophysical exploration. Geochemical indicators of hydrate include dissolved gas distribution,gas and organic compound composition in sediments, chlorinity, salinity, alkalinity of pore ﬂuid, and the isotope compositions of water. These indicators inform us about the origins of natural gases and gas hydrate formation mechanisms. During gas hydrate formation process dissolved ions such as Na+ and Cl− are excluded from the hydrate structure and only water molecules crystallize into cubic lattice structure (Hesse and Harrison, 1981). Surrounding pore waters initially become more saline during the process of hydrate formation. During hydrate crystallization the exclusion of salinity (chlorine) and intake of δ18O is due to the solidﬂuid isotope fractionation that causes preferential uptake of the heavy isotope δ18O in the solid phase and depletion in the ﬂuid (Hesse, 2003). During the dissociation of hydrates the release of pure water in the host sediments reduces the chlorinity. During the dissociation of hydrates release of heavy isotope water and its mixing up with lower order isotopic water component results in enrichment of δ18O in the host sediments pore waters. The δ18O values increase with increasing depth and appreciable higher values recorded in the hydrate bearing sediments. The observed combined anomalies of chlorinity and δ18O in the pore water chemistry of the host sediments provides a reliable measure for identiﬁcation of gas hydrates. Lower values of chlorine concentration in the hydrate stability zone may suggest the occurrence of hydrates even when the prominent geophysical signature (BSR) is found missing (Holbrook et al., 1996).

1. **Production Methods**

Release and production of methane from hydrate-bearing formations are associated with hydrate dissociation. Different methods have been proposed to enhance gas production (Demirbas, 2010). The most prominent methods are (i) lowering the reservoir pressure below the hydrate equilibrium pressure at the prevailing temperature, known as depressurization; (ii) raising the temperature above the hydrate equilibrium temperature at the existing pressure, normally known as thermal stimulation; and, (iii) shifting the thermodynamic equilibrium curve of hydrate by means of injection of inhibitors, such as methanol or brine, to decompose the hydrate. Combinations of these methods can also be used. In general, where conditions are suitable, it is believed that the depressurization technique would be the most economical and practical method in the production from gas-hydrate deposits (Grace et al., 2008).

* 1. **Depressurization**

The depressurization method is currently regarded as the most promising method among others. However, it still exists several inevitable issues, such as subsidence during the depressurization and hydrate reformation due to endothermic depressurization event. All the problems should be solved in the future. The problems could be relieved by using combined methods. Such as the combination of the depressurization and the gas swapping for mitigating the subsidence, and the combination of the depressurization and the thermal stimulation for mitigating hydrate reformation (Moridis et al., 2007). The NGH dissociation by depressurization can be divided into three stages: (1) Free gas produce in the early stage. With the reduction of system pressure, the associated free gas is rapidly produced and the gas production rate increases rapidly. (2) Gas release from hydrate dissociation in the second stage. Natural gas hydrate decomposition rate is larger because of the larger fractional surface area. (3) Surplus free gas release in the third stage. Decomposition rate gradually decreases with the smaller decomposition of the surface area. The depressurization technology is advantageous because of its low production cost, its lack of need for continuous excitation, its simple equipment, the convenience of the operation, and its applicability to larger deposits. However, only when there is a temperature and a pressure balance boundary can depressurization technology serve with a practical use (Collett, 2011; Timothy, 2011, 2014).

* 1. **Thermal Stimulation**

Simple depressurization appears promising in Class 1 hydrates, but its appeal decreases in Class 2 hydrates. The most promising production strategy in Class 2 hydrates involves co ombinations of depressurization and thermal stimulation. (Moridis et al., 2007). The concept of thermal stimulation is straightforward. Natural gas hydrates are heated in situ till the local temperature is away from the hydrate stability region. When hydrate decomposes, the entrapped gas is released from water cages and ﬂows through the wellbore to be recovered. External heat is supplied through wellbore or point sources. The thermal stimulation method dissociates hydrates by raising temperature above the hydrate equilibrium temperature. In the thermal stimulation method, the energy that takes in the dissociation and the production should not exceed the energy we can get from produced gases to meet a simple economic principle. The energy needed for the hydrate dissociation is governed by thermal characteristics of the hydrate-bearing region (Moridis et al., 2011). Compared with other technologies, thermal stimulation is advantageous for direct and quick heat action, the obvious effect of hydrate absorbing heat and decomposing, the controllable wellhead positions of the heat injectors, its miniscule influence on the environment, and its applicability to various types of hydrate deposits. But, it is disadvantageous because of its large heat loss and its very low energy utilization efficiency. Especially in the permafrost zone, where NGH deposits can be found, although the pipeline insulation layer is capable of heat preservation, the low outside temperature will consume heat.

* 1. **Chemical Injection**

As compared to depressurization and thermal stimulation, chemical inhibition as a recovery method has been relatively less studied. For chemical inhibitor technology, methanol chemicals (e.g. salt water, methanol, and glycol) are used as an inhibitor for the formation of NGH and as an accelerator for NGH’s dissociation, thus prompting the hydrate to dissociate more easily. Experiments show that the dissociation rate of NGH is related to the displacement, concentration, pressure and temperature of the inhibitor and the area of the injection interface between the hydrate and the inhibitor(Collett, 2011). In the Messoyakha hydrate gas field, inhibitors were injected into five wells, and they caused the average gas yield to increase by 4 times. Similar experiments were conducted for hydrate in the permafrost of Alaska, and it was proved that chemical inhibitor technology can effectively move the phase boundary to obtain an obvious gas recovery effect. Chemical inhibitor technology is characterized by a low energy injection during initial production. However, the problem with it is that it causes only a slow and inefficient dissociation of hydrate in the reservoir. The chemical reagent is expensive and less commercially viable, and it may pollute the environment (Timothy, 2011, 2014).

* 1. **CO2 Injection**

The exchange of CH4 in the NGH deposits with CO2, perceived as a win-win approach in that it boosts the production of CH4 and decreases the level of CO2, has been thoroughly considered. In regards to its mechanism, in a certain range of pressures, gas hydrates will dissociate and CO2 hydrates may occur and remain stable. Under the same conditions, the water wettability of CO2 is stronger than that of CH4; therefore, at a certain temperature and pressure, CH4 can be injected into the hydrate layer to exchange itself with CO2, and the released heat during the exchange can maintain the dissociation reaction of NGH (Yun-Ho, 2014; Komai, 2012). In 2012, the U.S. company ConocoPhillips and the Japan Oil, Gas and Metals National Corp. (JOGMEC) obtained success in their first field test of the CO2-CH4 exchange technique, managing to utilize gas hydrate deposits in the Prudhoe Bay area of the north slope in Alaska. Theoretically, the exchange process of the CO2-CH4 exchange technology is spontaneous, and the formation of CO2 hydrate helps to maintain the stability of the geological mechanics and reduces the possibility of a slope instability. However, the CO2 hydrate formed also hinders further contact between the CO2 and CH4 hydrate, thereby inhibiting the dissociation of NGH (Takeshi, 2011; Sakamoto, 2011).

1. **Challenges and Prospects**

With the gradual depletion of traditional energy such as oil and coal, natural gas hydrate has a wide range of distribution, huge amount of resources and low pollution characteristics which make it become “future energy”. The abundance of gas hydrate reserves is expected to be more than twice of the combined carbon of coal, conventional gas and petroleum reserves. Natural gas hydrate has changed the pattern of the world’s energy. The challenges and problems for gas hydrate exploration and development are listed as following:

(1) For NGH’s exploration, although a potential for characterizations of hydrate reservoir using seismic indicators has been reported in literatures, characterizing based only on seismic survey results is less reliable.

(2) For NGH’s development, it’s difﬁcult to produce methane from the NGH reservoir and assess hydrate recovery rates. Besides, locating potential resources, quantifying hydrate content, keeping process safe from geomechanical impacts from hydrate dissociation are worth considering.

(3) For the environment and application, Hydrate development should not only consider its economic beneﬁts, but also the ways of transporting the extracted natural gas to the market. Whats more, development of natural gas hydrate may do more harm to environment. Methane gas greenhouse effect is much greater than the carbon dioxide gas.

In the future, the researcher should pay more attention on how to develop nature gas from hydrate, such as do more work on hydrate simulation and hydrate production test. Besides, the properties of hydrates should be studied. The kinetics arena will represent the largest challenge for advancing the information on hydrates. Although we know quite a lot about what hydrates are, the question of how hydrates form is still very much unanswered. Finding the answers to such questions provides the intrinsic motivation for future research.

**Supplements**

Many thanks to all those people who asked the sensible questions in the last class, which made me interested in reviewing exploration and production technology of natural gas hydrate. Besides, let me take this opportunity to answer your questions in class: How to distinguish the source of natural gas hydrate from organic or inorganic gas? The controversy between organic and inorganic origins of hydrocarbon generation never stops, and so does natural gas hydrate. I found an answer: Biogenic methane is generated at 900 meters deep in shallow sea sediments, while thermal gas is slowly permeated from geological faults to form extremely thick flammable ice reservoirs. In addition, combustible ice converted from biogas is almost entirely methane.

Thanks for your reading very much, Professor Chen.

If there are any mistakes in this paper or you have any questions, please contact me by email at [21834055@zju.edu.cn](mailto:21834055@zju.edu.cn).

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