

Mining Gas Hydrate Status Quo of Flammable Ice in Globe wide Review

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Abstract. Flammable ice, also known as methane hydrate, is a promising clean energy source that has the potential to significantly contribute to mitigating the effects of climate change. This study delves into the fascinating world of gas hydrate mining, examining pivotal historical milestones and the current state of extraction efforts in key countries such as China, the United States, Japan, and Canada. By analyzing these nations' approaches, the research sheds light on the unique characteristics and inherent limitations of four distinct mining techniques: depressurization, thermal stimulation, chemical injection, and CO₂ replacement. The study meticulously uncovers the multifaceted challenges that the industry faces, from technological barriers to environmental concerns, and explores the prospects of flammable ice as a viable energy alternative. It also offers a comprehensive overview of the current research landscape, identifying knowledge gaps and suggesting potential avenues for future exploration. The findings are presented with the aim of informing policymakers and technologists, providing them with valuable insights that could guide the development of more efficient and sustainable mining practices. This research is not just academic; it is a call to action for the scientific community to innovate and collaborate in harnessing the power of flammable ice to combat climate change and secure a cleaner energy future.

Keywords: methane hydrate, reserves, climate change.

1. Introduction

Flammable Ice also called as combustible ice, methane clathrate and gas hydrate is a solid compound formed by methane molecules and surrounding water molecular cage formed by hydrogen bonds. This solid ice-like compound is usually formed under specific physical conditions such as low temperature, high pressure, water salinity, etc [1]. It also means that flammable ice is very sensitive to environmental conditions, so the mining of it is difficult. Because combustible ice is only in a stable state under certain conditions, once the temperature and pressure change, the structure of combustible ice will change and lead to the outflow of methane gas, and the global warming potential (GWP) of methane is around 37 ± 10 over a hundred-year time horizon. This implies that 1Tg of methane released over a one-hundred-year time horizon is equivalent to 37 ± 10 Tg of carbon dioxide released [2]. If gas hydrate is not properly exploited, it will certainly cause great damage to the natural environment. Over the years, people have been seeking an alternative energy to cope with the growing international energy demand, while flammable ice as a new type of energy with huge reserves undoubtedly and great prospects for exploitation, one cubic meter of flammable ice can release up to 164 cubic meters of methane gas, which will undoubtedly alleviate the human energy crisis to a great extent [3]. China, as the world's second greatest economy, has huge energy needs. The estimate of the South China Sea gas resource is 65 Cubic Terameter, equivalent to 65 billion tons of petroleum [4]. In addition to China, other countries like the US, Canada and Japan have been trying to mine gas hydrate [5].

2. Global View of Gas Hydrate

2.1. In China

2.1.1. Reserves

China has abundant reserves of flammable ice, with a total of about 84 trillion cubic meters, distributed in descending order: 64.96 trillion cubic meters in the South China Sea, 12.5 trillion cubic meters in the Tibetan Plateau, 3.38 trillion cubic meters in the East China Sea, and 2.8 trillion cubic meters of Permafrost in the Northeast of China [6].

2.1.2. Current Status

On May 10, 2017, the China Geological Survey completed the first production test in the Shenhu area of the South China Sea, which lasted 60 days and contained 309,000 cubic meters of gas [7-9]. The storage layer of natural hydrates in the Shenhu area of the South China Sea is mainly a silty clay layer, which accounts for more than 99.5% of the global reserves of natural gas hydrates and is difficult to exploit. This is also the first experiment of natural gas hydrate exploitation in clayey-silty soil layers in the world. From October 2019 to April 2020, China carried out the second trial mining of combustible ice in the Shenhu area of the South China Sea, and in the 30-day continuous gas production process, a total of 861,400 cubic meters of gas was produced, with an average of 28,700 cubic meters of gas produced every day, both of which were significantly higher than the cumulative gas production and daily gas production of the first trial production, and the gas produced by the production test is mainly methane, with an average content of more than 99% [8, 9].

2.2. In the United States

2.2.1. Reserves

Natural gas hydrates in the United States are mainly distributed in the North Slope of Alaska and the New Gulf of Mexico, which according to the latest data from the United States Address Survey estimated that the undiscovered and recoverable natural gas hydrates in the North Slope of Alaska are about 54 trillion cubic feet, and the Gulf of Mexico contains up to 6,700 trillion cubic feet of gas hydrates [10].

2.2.2. Current Status

The U.S. Department of Energy (DOE) has awarded a \$79.3 million grant to The University of Texas Institute for Geophysics to sample and analyze methane hydrate deposits in the Gulf of Mexico for an 11-year (2014-2026) research program that includes expeditions to find, drill, and sample methane hydrate deposits, as well as study the feasibility of decompressing methane hydrate production methods [11]. In 2018, NETL and JOGMEC, in collaboration with JOGMEC, USGS and Alaska Petroleum Technical Resources, and in collaboration with Prudhoe Bay unit owners, drilled a formation test well (STW) that successfully demonstrated the presence of gas hydrates at the site and suitability for future long-term test production. Well Hydrate-01 (STW) began drilling in Kuparuk 7-11-12 on the North Slope of Alaska, and the program is targeting long-term drilling of 12 to 24 months [12].

2.3. In Japan

2.3.1. Reserves

The ocean around Japan contains rich gas hydrate reserves, mainly in the Nankai Trough, and it is estimated that the reserves of methane hydrate in Japanese waters are about 44-47,000 cubic meters [13].

2.3.2. Current Status

Japan established the first national methane hydrate research project in 1993 and was the first country in the world to invest significant funds in methane hydrate extraction research. In 2013, Japan

conducted the world's first gas hydrate extraction experiment at the Daini Atsumi Knoll in the South East Sea basin near Honshu Island. After seven days of mining, the experiment was halted due to sand production, and the volume of gas extracted reached 12,000 cubic meters [14]. It was not until 2017 that Japan's second attempts to conduct a mining experiment at the Nankai Trough was halted again due to abrupt sand production on the 12th day after mining, and the second well was then deployed on May 31, and the flow test lasted for 24 days, with no sand production problems, and the cumulative gas production was about 5.7 times that of the first experiment of the year [14][15].

2.4. In Canada

2.4.1. Reserves

Canada has a vast continental shelf and Arctic permafrost, which contains rich reserves of combustible ice resources, Canada's combustible ice distributed in the McGan-delta-beaufort Sea, the Arctic Archipelago, the Pacific rim and the Atlantic rim, The amount of methane in Canadian methane hydrates is estimated to be 1.63 to 30 times that of in-situ hydrocarbon gas, which is a significant reserve [16].

2.4.2. Current Status

In 1998, the Mallik 2L238 gas hydrate research well was set up at the Mallik site in the Mackenzie Delta, Canada, and the well discovered gas hydrate and produced a gas hydrate core in the 897-952 m interval [17]. In 2002, nine organizations from five countries, including the Geological Survey of Canada, the Japan National Petroleum Corporation, the German Institute of Geosciences, the U.S. Geological Survey, the U.S. Department of Energy, the Gas Supply Corporation of India, and the Oil and Gas Corporation of India, jointly invested in the Mackenzie Delta for gas hydrate exploration. This project is the first natural gas hydrate exploitation test in the history of the area, and also the first such large-scale international cooperative research on natural gas hydrate exploitation in the world [18].

3. Methods and Limitation

3.1. Thermal Stimulation

Thermal activation method refers to heating the hydrate stable layer through four injection methods: hot water injection, steam injection, shaft electric heating and low-frequency electric heating under a certain pressure to obtain methane in the hydrate [19]. However, this method has defects, in the process of transporting heating medium through adiabatic pipes, the thermal activation method can obtain methane in the hydrate. Permafrost reduces the effective heat transferred to the hydrate enriched layer during fluid transport, resulting in low gas production and poor energy efficiency [20].

3.2. CO₂ replacement

Carbon dioxide replacement method takes advantage of the low pressure required for the stability of carbon dioxide hydrate to replace methane molecules in the hydrate cage by injecting carbon dioxide into methane hydrate [20]. This method is undoubtedly of great significance for environmental protection because it can fix carbon dioxide. It has been shown that the thermal stimulation method used in the exchange process of carbon dioxide replacing methane in methane hydrate can significantly improve the displacement efficiency of methane [21].

3.3. Depressurization

Natural gas hydrate is stable at high temperature and low pressure, and the decompression method takes advantage of this feature to lower the reservoir pressure to the stable range of natural gas hydrate to obtain natural gas [22]. The decompression method is the most effective of the three methods, which can be used alone or combined with the other methods [19]. However, the decompression

method also has its limitations. The methane produced by the decompression method has decreased the rate of hydrate decomposition and the production has decreased with the increase of time due to the influence of mass-transfer-limitation effect [23].

3.4. Chemical inhibitor method

The chemical inhibitor method changes the stable structure of the hydrate by injecting a thermodynamic inhibitor (THI), kinetic inhibitor (KHI) and anti-caking agent (AA). Compared with other technologies, the chemical inhibitor method has high cost and large consumption, which may lead to methane leakage during exploitation and cause climate problems [24].

4. Challenge and Prospects

4.1. Short-term Challenge

The exploitation of natural gas hydrate is faced with many difficulties. Firstly, the cavitation of natural gas reservoirs may lead to formation deformation and instability and other mechanical problems during exploitation [25, 26]. In order to deal with these problems, the transformation of hydrate reservoirs is very important. Secondly, due to the nature of the natural gas hydrate itself, the temperature must be strictly controlled during the mining process to avoid the decomposition of natural gas, which brings great tests to the drill cooling process. In addition, due to the porous structure layer where the hydrated natural gas reservoir is often mixed with a large amount of sediment, and the weak cement of hydrate is easy to produce sand during the mining process, resulting in pipeline blockage and gas recovery failure. Two experiments in Japan in 2017 failed due to sand blockage. Finally, natural gas, as a greenhouse gas, is likely to cause serious climate disasters if it leaks during exploitation [2].

4.2. Long-term Challenge

Once the commercial exploitation of hydrated natural gas is successful, its huge reserves will have an impact on the existing international energy market, and traditional fossil fuels may plummet, resulting in disputes between traditional fossil fuel exploitation countries and hydrated natural gas exploitation countries, so it is very important to establish reasonable exploitation and trade regulations. Not only that, natural gas is not a completely clean energy, it will still release carbon dioxide, a greenhouse gas, so the pursuit of sustainable energy cannot stop.

4.3. Prospects

As the international energy demand is increasing day by day, hydrated natural gas, as a resource with abundant reserves and relatively little pollution, undoubtedly has a good prospect. Among them, the successful exploitation of natural gas in the Shenhua area of China undoubtedly encourages the expectation of all countries in the world for natural gas, which proves the correct application of current technology. How to solve the problem of stability and production improvement in the future of natural gas extraction will be the goal of many scientists in the future.

5. Conclusion

This study reviews important events and recent developments in the history of combustible ice mining in China, the United States, Japan and Canada, and introduces the characteristics and limitations of four natural gas hydrate mining methods. The significance of this study is that it reveals the current situation and future development trend of combustible ice mining through comparative analysis of mining conditions in different countries, and provides suggestions for relevant policy formulation and technical improvement. Nevertheless, there are certain limitations in this study, such as limitations of data sources and analysis methods, which may affect the comprehensiveness and accuracy of the conclusion. In the future, with the continuous progress of technology and the

strengthening of international cooperation, countries are expected to make greater breakthroughs in the field of combustible ice mining. However, how to achieve economic benefits and sustainable energy development under the premise of ensuring environmental safety will be an important issue facing all countries. It is hoped that the analysis of this paper can provide useful reference for related research and promote the cooperation and exchange in the field of combustible ice mining.

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