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The status of natural gas hydrate research in China: A review

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ABSTRACT

Over the past century, fossil fuels have provided the majority of China's energy. However, their extensive utilization leads to a shortage and environmental pollution. Recently, submarine and permafrost gas hydrate deposits have been investigated as a possible clean and sustainable energy source by governmental institutions, research organizations, and energy industries in China. The primary objective of this paper is to review the potential studies pertaining to gas hydrate exploration and resource assessment, the safe and efficient exploitation of gas hydrates and the basic properties of gas hydrates. To date, there are over 20 institutions and organizations in China committed to gas hydrate investigation, among which the Guangzhou Marine Geological Survey (GMGS) and the Chinese Academy of Geological Sciences (CAGS) etc. primarily focus on gas hydrate exploration research, while the China National Offshore Oil Corporation (CNOOC) Research Center, Guangzhou Institute of Energy Conversion (GIEC) and China University of Petroleum-Beijing (CUPB) etc. concentrate on gas hydrate mining technologies. In this paper, the occurrence and exploration of gas hydrates in both permafrost regions and the continental slope of China have been determined from numerous research contributions and are presented. Moreover, the latest progress in gas hydrate fundamental studies, including hydrate phase equilibria, hydrate formation mechanisms, hydrate thermal physical properties and the acoustics and resistivity characteristics of gas hydrates are briefly reviewed, and relevant data are gathered and compared. Emphasis is also placed on gas hydrate mining technologies and gas production using depressurization methods, thermal stimulation methods or other methods. Furthermore, the security of natural gas hydrate-bearing sediments during gas production and the environmental impacts of gas hydrate are identified. With additional financial and political support and advanced research facilities, research on gas hydrates in China is progressing rapidly but is still in its early developing stage, thus, future work should be undertaken with greater diligence.

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1. Introduction

Fossil fuels currently satisfy approximately 85% of the world's commercial energy needs [1]. Considering that conventional fossil fuel resources are being exhausted and the continuously increasing energy demand, locating a sustainable alternate energy source is essential and urgent. Gas hydrates, which exhibit high energy density, are clean, and for which a large amount of resources are available, are generally accepted as a potential strategic energy form for sustainable development [2]. Over the last decade, there has been a tremendous increase in gas hydrate studies, and more capital has been invested and more governmental agencies are becoming involved in this popular field.

Gas hydrates are ice-like solid crystalline compounds formed by small gas molecules, such as methane, with cages of water framework called hosts [3]. To date, three types of gas hydrate structures have been studied: structure I, structure II and structure H. Gas hydrates are formed under suitable conditions of low temperature and high pressure, which implies that gas hydrates are found in two different geographic settings: the permafrost and the continental slope. One of the most important reasons why gas hydrates attract the world's attention is that 1 m^3 of gas hydrate may contain as much as 180 m^3 of gas at standard temperature and pressure, and the amount of carbon in hydrate form is twice the total carbon amount in fossil fuel form on the earth [4]. Gas hydrates were first discovered in laboratory studies in 1810; however, no further attention was paid to these materials until the 1930s, when petroleum engineers observed that hydrates contributed to the plugging problem of natural gas transport pipelines [5]. In the past four decades, with the gradual discovery of large amounts of natural gas hydrate sediments and a better understanding of the properties of gas hydrates, researchers have increasingly devoted themselves to the study of gas hydrates, more scientific achievements have been contributed and more high-quality papers have been published. Meanwhile, new technology based on hydrate studies are being developed, including gas separation [6], gas storage and transportation [7–9] and CO_2 sequestration [10].

In China, research on nature gas hydrate began in the 1990s when a research group at the China University of Petroleum-Beijing (CUPB) initiated fundamental studies on gas hydrates [11]. Hydrate phase equilibria and the kinetics of hydrate formation and dissociation were first studied in 1995 at the High Pressure Fluid Phase Behavior and Property Research Laboratory of CUPB [5]. In the mid-1990s, the Guangzhou Institute of Energy Conversion (GIEC) of the Chinese Academy of Sciences (CAS) began studies on the hydrate-based thermal energy storage technique. Currently, there are more than 20 research groups in China working in various fields of hydrate investigation, especially in studies on gas hydrate exploration and exploitation. Among these research organizations, GMGS, the Institute of Mineral Resources (IMR) of CAGS, the Ocean University of China (OUC) and the Institute of Oceanology, Chinese Academy of Sciences (IOCAS) etc. mainly focus on gas hydrate exploration studies, and studies on gas hydrate exploitation technologies are chiefly conducted by the CNOOC Research Center, GIEC and CUPB etc. In addition, Dalian University of Technology (DUT), Zhejiang University (ZJU), China University of Geosciences (CUG), Guangzhou Institute of Geochemistry (GIG), the Institute of Geology and Geophysics (IGG) and Qingdao Institute of Marine Geology (QIMG) etc. also play a significant role in gas hydrate investigation. Meanwhile, many research projects have been subsidized by government departments, including the National High Technology Research and Development Program (863), the National Key Basic Research and Development Program (973), National Science and Technology Major Projects, and the National Natural Science Foundation.

In this study, the latest progress in gas hydrate-related research in China is briefly reviewed, including the exploration of natural gas hydrate, basic property research, exploitation technology and the security of nature gas hydrate exploitation.

2. Natural gas hydrate exploration in China

Natural gas hydrates are widely distributed in permafrost regions and the continental slope, where the temperature and pressure conditions are suitable for formation. It is estimated that the global amount of hydrate-bound gas is approximately 2.5×10^{15} m^3 for methane [12]. More than 230 natural gas hydrate deposits (NGHD) have been discovered worldwide in 79 countries [3]. Recently, the exploration of natural gas hydrates has been active around the world in seafloor areas and permafrost regions.

In China, natural gas hydrates exist abundantly in both permafrost and seafloor areas. In the Qinghai–Tibet plateau permafrost area, geological, geophysical and geochemical studies have indicated the presence of gas hydrates. Samples of gas hydrates were collected in Qilian Mountain permafrost during 2008–2009, representing the first discovery of gas hydrates in permafrost of China [13]. The amount of natural gas caged in hydrates in permafrost regions of the Qinghai–Tibet Plateau ranged from approximately 1.2×10^{11} to 2.4×10^{14} m^3 [14]. In addition, the existence of gas hydrates in the South China Sea (SCS) has been geologically, geophysically and geochemically confirmed. The preliminary results indicated that the estimated inventory of natural gas in the SCS was 6.5×10^{13} m^3, i.e., 65 billion tons of oil equivalent with a 50% confidence level [15].

2.1. Gas hydrate exploration in permafrost regions

The Qinghai–Tibet Plateau, located in southwestern China, extends for a maximum of 2945 km from east to west and for 1532 km across 13° of latitude. A considerable portion of the Qinghai–Tibet Plateau is underlain by permafrost with different thicknesses. The latest studies have indicated that the permafrost in the Qinghai–Tibet Plateau accounts for nearly 80% of the total permafrost area in China (2.15×10^6 km^2) [16]. The particular geographical and climatological conditions provide suitable temperature and pressure conditions for gas hydrate formation. In recent years, geological, geophysical, and geochemical investigations were conducted in the Qinghai–Tibet plateau permafrost, resulting in prospective gas hydrate occurrence areas, relevant resource assessment and sample collection [17–20].