International Conference on Applied Energy 2019
Aug 12-15, 2019, Västerås, Sweden
Paper ID: 899

ENVIRONMENTAL IMPACTS OF METHANE SEEPAGE FROM MARINE HYDRATE EXPLOITATION: CHALLENGES AND FUTURE PERSPECTIVE

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ABSTRACT

With rapid depletion of conventional energy resources and the promotion of low-carbon energy development, natural gas hydrate (methane hydrate) has been attracting increasing attention over the governments, scientists, and industries, for its huge reserves and less environmental pollution after combustion. Japan and China have successfully conducted trail production and harvested natural gas from marine hydrate reservoir, which ignites the hope of commercial natural gas production by natural gas hydrate exploitation. However, natural gas was buried in the sediment under the deep ocean sea floor, and gas hydrate serves as effective cementing agent among the sediment particles. Drilling production well and gas production from hydrate reservoir may result in a series of natural geological hazards. Methane leakage from the hydrate reservoir and the migration of methane into the overlying water column can cause ocean acidification. Furthermore, once abundant methane bubbles escaped into the atmosphere will influence the carbon cycle and global climate change. Quantitative research of environmental and ecosystem impact of methane leakage from natural gas hydrate exploitation is indispensable for promoting the commercial exploitation process of natural gas hydrate. This paper outlines the potential environmental impact of natural gas exploitation in detail, which provides references for future natural gas hydrate exploitation and utilization.

Keywords: natural gas hydrate, clean energy, methane seepage, environment impact, marine ecosystem

1. INTRODUCTION

Natural gas hydrates are crystal compounds which are stably existed in the permafrost region and the deep ocean continental margin with the conditions of high pressure and low temperature[1]. Nowadays, global energy demand increases continuously with the results of rapidly urbanization, expanding industries, growing populations, and economic growth. With the imperative sustainable development, a diversity of clean energy supply structure is essential for addressing the increasing energy demand and ensure energy security[2]. Natural gas hydrates occurred widely in the ocean region. About 85% of the Pacific Ocean and 95% of the Atlantic regions contain gas hydrates [3]. It is estimated that global reserves of natural gas hydrate ranges from 1000 to 10,000 GtC, which equivalent to approximately from 2×10^{15} to 2×10^{16} m^3 of methane gas (STP)[4]. With the merits of high energy density, huge reserves, and low carbon content, natural gas hydrates are deemed as an important alternative energy.

During the past decades, production schemes of gas production from natural gas hydrate have been widely investigated[5]. In addition, field tests of natural gas hydrate exploitation have been successfully conducted in the permafrost region and the marine area. Japan firstly successfully harvested natural gas from the marine hydrate reservoir in Nankai Trough in 2013. Later on, China carried out the first successful field test of steady gas production from fine-grained marine hydrate reservoir[6].

Hydrate stability is very sensitive to the surrounding environmental conditions. Once the equilibrium stable environment of gas hydrate was broken by human and geological activities, huge amount of methane can be released from the natural gas hydrate and seep into the marine sediment, overlying water column, and even escape into the atmosphere. Events reveals that approximately 3×10^{12} t carbon was released from the gas hydrate reservoir with the result of global temperature growth in the Neoproterozoic[7]. Moreover, the frequently occurred seafloor slope instability in Norway and New Zealand was considered as closely related to methane hydrate dissociation[8]. In addition, methane seep from gas hydrate dissociation is strongly connected to the benthic ecosystem[9]. However, during the past decades, gas hydrate research mainly focused on resource exploration, mining technology, and the corresponding transformative technology. Few attention has been paid into the environmental impact research. Currently, there is a huge gap between gas hydrate commercial exploitation and the environmental risk control.

This paper outlined the environmental impacts of methane seep from marine hydrate dissociation. Moreover, the dynamics and challenges of environmental impacts investigation of methane seep by gas hydrate dissociation was reviewed. The future prospect and policy were also analyzed.

2. ENVIRONMENTAL IMPACTS of METHANE HYDRATE

2.1 Factors influencing methane hydrate instability

In the deep marine condition, hydrate stability was controlled by the environmental conditions of pressure, temperature, salinity, methane solubility, and the fluxes of total energy and mass. The upper layer of the hydrate occurrence zone (HOZ) is generally tens of meters below the seafloor. The bottom layer of the HOZ exists at a shallower depth than the base of the hydrate stability zone (HSZ). Once the ambient conditions are outside the HSZ by natural or anthropologic activities, methane hydrate gets unstable.

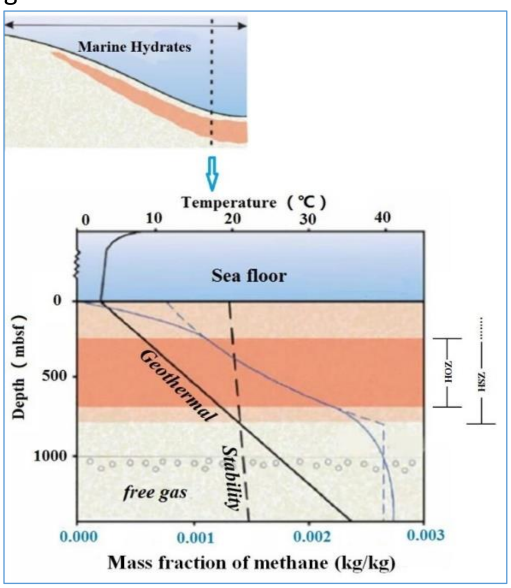

Fig 1 Hydrate occurence zone (HOZ) and hydrate stability zone(HSZ) in marine hydrate system[10]

2.2 Geological Hazard caused by methane seep from hydrate dissociation

Hydrate exists as solid form in the sediments. As shown in Fig.2, environmental condition change can cause hydrate dissociation, triggering large scale submarine landslide. This submarine landslide may weaken the sediments and making the sediments more incline to slope failure, which induce tsunami and damage marine infrastructure. It is generally accepted that hydrate dissociation will increase pore pressure and decrease sediment strength. Gas and water release from hydrate dissociation produce volume expansion and excess pore pressure [11]. Excess pore pressure reduces the effective stress and frictional strength of the sediment, making the hydrate-bearing sediment more vulnerable to destabilization.

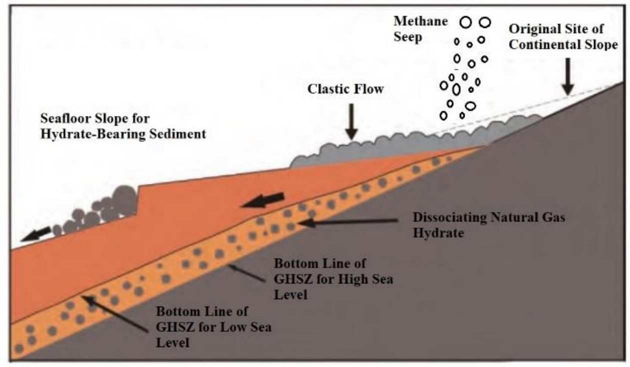

Fig 2 Conceptual sketch of submarine landslides caused by hydrate dissociation

2.3 Marine ecological environmental influenced by methane seep from hydrate dissociation

As shown in Fig.3, methane released from hydrate dissociation transported along the fractures/faults to the ocean bottom, fueling a unique ecosystem characterized by chemosynthesis, abundant biomass, and less biodiversity. This unique ecosystem was honored as oasis in the desert. Methane seep from hydrate dissociation supplies plentiful organic matter to the microbes and animal-microbe symbioses which depends methane as energy. It is estimated that the contribution of this chemosynthetic productivity approximately accounts for 7% of the total carbon in the ocean[12]. The biological community acts as benthic filter of methane leakage through aerobic and anaerobic oxidation of methane (AOM). As the largest sea bed is anoxic, the majority methane sink in the deep ocean is through the AOM process in which sulfate acted as the electron acceptor shown in Eq.1:

$$CH_4 + SO_4^{2-} \rightarrow HCO_3^- + HS^- + H_2O \qquad (1)$$

Meanwhile, methane seep promotes carbonate deposition, keep transforming the seafloor morphology and the sub bottom characteristic, creating a unique habitat for the cold seep biology.

The proportion of methane consumed by the biological system mainly depends on the fluid flow rate and methane flux. When the fluid flow rate is high, the methane consumed in the benthic ecosystem is less than 20%, and when the fluid flow is slow, more than 80% of the methane can be absorbed by the biological community in the cold seep system. If huge amount of methane leakage occurred during natural gas hydrate exploitation, the methane flux exceed the absorption capacity of the biological system, with the result of ocean acidification, even the superfluous methane will escape into the atmosphere.

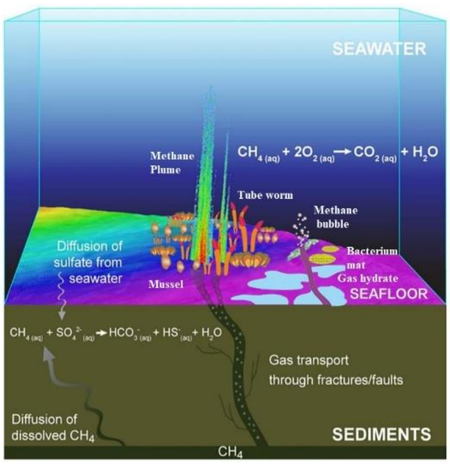

Fig 3 Benthic ecosytem influenced by methan seep from hydrate dissociation[13]

2.4 Climate Change caused by methane seep from hydrate dissociation

Methane is a kind of more potent greenhouse gases than carbon dioxide. Researches indicated that about 1.4 to 2.8×10^{18} g methane from oceanic hydrate dissociation escaped into the atmosphere, with the result of global surface temperature increases by approximately 5 °C [14] in the Late Paleocene Thermal Maximum. Some researchers take a skeptical view on hydrate commercialization because anxious about the catastrophic effect to climate change by huge amount of methane leakage.

Methane monitoring at the sea-air interface was carried out during the field tests of methane hydrate exploitation in the Nankai Trough of Japan, and in the South China Sea in China. Results shows that there was no obvious sign of methane escaped into the atmosphere.

Seafloor emissions and sea-air methane fluxes are two important components in determining the sensitivity of gas hydrate dissociation to climate change. As for the global level, methane hydrate has not realized long-term exploitation, few data and investigation can be obtained from the real environment. The current research of hydrate sensitivity to climate change mainly through numerical simulation. Some published results showed that the response of methane dissociation to climate change is mild, because the majority of the discharged methane has been absorbed by the overlying water column.

3. DYNAMICS OF ENVIRONMENTAL IMPACTS BY NATURAL GAS HYDRATE DISSOCIATION

So far, hydrate has not realized longer-term exploitation in a global context. The fate of discharged methane from hydrate dissociation remains uncertain. During the field tests of the Nankai Trough and the Shenhu Area, methane leakage around the drilling wells has been monitored in a short term. However, the longer-term environmental impact of hydrate dissociation by anthropogenic activity remains undiscovered. How much methane will seep from the up-dip limit continental hydrate stability zone before, during an after the drilling and gas production process? How the escaped methane affects the ocean chemistry, the sea-to air flux methane in three-dimensional scale, and the synergistic effect of methane flux and the benthic ecosystem requires to be clarified.

Up to now, it is accepted that hydrate exploitation and application is imperative. The question is how far it will come? One of the most important bottleneck restrictions is the quantification research of the environmental impact caused by methane seep from hydrate dissociation, and the corresponding warning and control theory and techniques.

Monitoring technique and theory is the basic conditions determines the hydrate environmental level. Long term and real time monitoring techniques in geological and geophysical evidence should be developed to identify the critical conditions of methane leakage during hydrate exploitation[6]. Some advanced monitoring and experimental techniques such as manned deep-sea submersibles can also play important role in detecting and identifying the critical impacts in ocean water column. Manned deep-sea submersibles also significant advantage over precise sampling around the methane seep area, which will improves the in situ experimental level.

As shown in Fig.4, different levels of methane leakage during hydrate exploitation process will cause different impacts. There are four scenarios. Fig. 4a denotes the mild leakage that only trace amounts of methane was discharged, and all of the free methane was absorbed by the sediment. In Fig. 4b that more free methane escaped from the hydrate-bearing layer and the production well, and the free methane entered the seafloor. All the escaped methane was absorbed by the sediment or reformed secondary hydrate, that is, there is no methane diffused into the overlying water column. As shown in Fig.4c, more methane seeped into the sea water and cause ocean acidification. Moreover, Fig. 4d shows that the worst situation is that huge amount of leakage occurred, the redundant methane escaped into the atmosphere.

Nowadays, there is no standard system evaluating the different situations in Fig.4 all over the world. A comprehensive set of monitoring technique, in situ experimental research system, methane leakage standard system, and modelling research required to be established before methane commercial production.

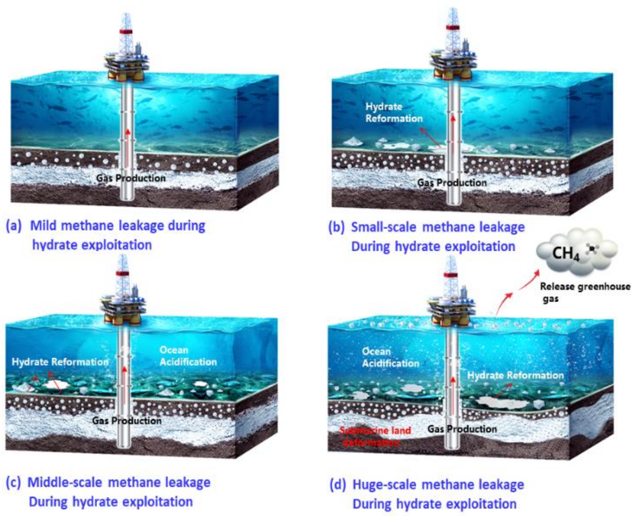

Fig 4 Different levels of methane leakage during hydrate exploitation process and the conrresponding environmental impact

4. CONCLUSIONS

Natural gas hydrate is a promising alternative energy, with the merits of high energy density, huge reserves, and low carbon content. Environmental impact research must be resolved before commercial production. This work reviewed and outlined the environmental research of methane seep from methane hydrate dissociation. The corresponding countermeasure is that a comprehensive set of monitoring technique, in situ experimental research system, methane leakage standard system, and modelling research required to be established before methane commercial production.

ACKNOWLEDGEMENT

The authors are grateful to the editors and reviewers for their kind help. The authors also would like to acknowledge the financial support for this research received from the National Natural Science Foundation of China (51806251 and 51676190), and Youth Innovation Promotion Association CAS (2019338).

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