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Editorial: Gas hydrate and hydrate technology for greenhouse gas mitigation

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Editorial on the Research Topic
Gas hydrate and hydrate technology for greenhouse gas mitigation

Hydrate-based carbon dioxide separation, capture, utilization and storage (CCUS) is a new carbon emission reduction technology. Compared with the traditional technologies, it has the advantages of high energy efficiency, large separation capacity, simple process and environment-friendly. Since the 1980s, the research on gas hydrate and hydrate-based technology has gradually attracted more and more attention and become one of the focus of research (Li et al., 2016). Presently, the research is mainly focused on solving the two aspects restricting the industrial application of hydrate technology, low gas consumption and slow hydrate formation rate, including thermodynamics, kinetics, micro mechanism of hydrate-based CO_2 separation and capture and hydrate-based utilization and storage of CO_2, such as CO_2-CH_4 replacement and exploitation of natural gas hydrate (NGH) (Xu et al., 2019).

Promoting gas hydrate formation and enhancing CO_2 consumption during the hydrate formation under a certain temperature and pressure are the two key issues to transform hydrate-based technology from experiment to commercial application. This is also the top priority of current related research. The formation of gas hydrate is essentially the transformation of gas-liquid solid phases, involving heat and mass transfer and interfacial reaction. Increasing the gas-liquid contact area and promoting the mass and heat transfer in the process of hydrate formation are considered to be the two directions that researchers focus on to solve the commercial application of the hydrate technology. Therefore, researchers have proposed many physical/chemical methods such as mechanical stirring, bubbling, spraying, porous media and emulsification to promote gas-liquid contact during hydrate formation (Ma et al., 2016). However, despite years of research, the bottleneck restricting the commercial application of the hydrate technology has not been solved. Therefore, researchers return the research focus from dynamics to thermodynamics. It is recognized that the problem can be solved fundamentally only after

the affecting mechanism of the gas hydrate formation is deeply acknowledged from the micro level. For example, by adding surfactant to water, reducing the solution interfacial tension and making more gas evenly dispersed in the liquid phase, the gas-liquid contact area is promoted from the mesoscopic and even microscopic. This way is proven to not only significantly improve the hydrate formation rate, but also improve the gas consumption. For another example, by using the chemical polarity and charging characteristics of gas and solution, an electric field is introduced into the hydrate formation process to make the gas-liquid miscible phase move each other under the action of the electric field, promote the gas-water contact from the micro level, and also effectively improve the formation rate of natural gas hydrate Zhao et al. However, this does not mean that the stronger the electric field, the better the effect of promoting the gas hydrate formation, because the higher Joule heat brought by the strong electric field and the ionization of metal ions with higher concentration are not conducive to the formation of gas hydrate. However, through this study, we can also determine that promoting sufficient and uniform gas-liquid contact between gas and water at the mesoscopic or micro level can more effectively solve the problems of slow hydrate formation rate and low gas consumption caused by difficult gas diffusion in the liquid phase during the hydrate formation. Therefore, we have got such a revelation: for future industrial applications, the increase of CO_2 hydrate formation rate will also be mainly based on micro water vapor contact, supplemented by macro stirring or spray.

Hydrate-based CO_2 capture technology can help to capture a large amount of CO_2 from power plant flue gas or other centralized emission sources of CO_2. However, for carbon emission reduction, CO_2 capture is not the ultimate goal. The ultimate goal is to convert the captured CO_2 into other types of carbon containing products for reuse, or realize CO_2 permanent storage while using CO_2. Hydrate-based CH_4-CO_2 replacement extracting CH_4 from NGH is considered to be a technology with great potential and can achieve win-win results in carbon emission reduction and natural gas exploitation, and it is considered as a new way and technology to realize CCUS, because CO_2 is also stored in the form of CO_2 hydrate solid while realizing CH_4 exploitation. Currently, the biggest problem of CH_4 extraction from NGH by hydrate-based CH_4-CO_2 replacement method is the low production efficiency. The fundamental reason is the difficulty of CO_2 gas diffusion in NGH reservoir (Wang et al., 2021). In fact, the basic condition for the replacement is that the concentration of CO_2 in the peripheral gas phase of CH_4 hydrate should exceed 20%, because the higher the CO_2 concentration, the more opportunities to promote the mass transfer reaction between CO_2 and CH_4 in hydrate cage. Due to the porous structure in NGH, the size of pores, capillary effect in the NGH and input pressure are the main factors affecting CO_2 diffusion. Without changing the physical structure of NGH and increasing the compression cost, the gas molecules smaller than CO_2, such as H_2 or N_2, are introduced in the process of CH_4-CO_2 replacement to enhance the CH_4-CO_2 replacement efficiency. The research showed that due to the small size, H_2 or N_2 molecules can smoothly pass through the small pores of NGH and expand the pores in the NGH so that CO_2 can pass through relatively smoothly, and finally result in the improvement of the replacement efficiency by around 16% (Ding et al.). In fact, this method has been verified as early as last century. American researchers used CO_2/N_2 mixture to extract CH_4 from NGH in permafrost region in 2007, but this method has not been tested in seafloor (Oyama and Masutani, 2017). Because the small molecule H_2 or N_2 can not be stable in the stratum in the form of hydrate like CO_2, and it may lead to some other problems such as gas leakage, unless it can completely recovered after the extraction. Therefore, future research will focus on improving the efficiency of replacement and storage, while more energy needs to be invested in the recovery and reuse of small molecular gases.

Moreover, the application of the hydrate-based technology in NGH exploitation is of great significance to alleviate the fossil energy crisis faced by human sustainable development. Different from oil and gas reservoirs, the NGH exists in the stratum in the form of solid and mixed with sediments to support the stability of the stratum. Therefore, there is a risk of geological collapse in the NGH exploitation. In addition, there are various forms of NGH in the stratum. The process of NGH exploitation is accompanied by the production of a large amount of water and sand, which increases the difficulty of exploitation. At present, only Japan and China have carried out experimental NGH exploitations in the Nankai Trough of Japan and Shenhu sea area of China, but they have not lasted for more than 2 months because of the problem of producing a large amount of water and sand (Yu et al., 2021). Therefore, relevant research still focuses on the simulation and experimental optimization of the exploitation technologies (Ruan et al., Yu et al., Yamamoto and Nagakubo).

Gas hydrate technology serving CCUS is receiving more and more attention. As a new technology different from the traditional one, the hydrate technology is the only technology that can synchronously realize CO_2 separation, capture, utilization and storage, and has potential competitive advantages. However, the current research is still in the experimental stage, especially the research on the continuous process of CO_2 separation, capture, utilization and storage has not yet appeared, which needs to be strengthened in the later research.

Author contributions

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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