

Review

Laboratory Synthesis and Characterization of Natural Gas Hydrates for Sustainable Gas Production from Hydrate-Bearing Sediments

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Abstract

Natural gas hydrate (NGH) deposits represent a vast and clean energy source. However, sustainable gas production from these resources remains an unsolved technical problem due to potential geohazards and climate challenges. A critical issue in this regard is the difficulty of obtaining in situ samples, which are essential for detailed laboratory studies of NGH's geomechanical and chemical behavior for safe and green gas production after hydrate dissociation. Currently, the retrieval of representative samples from NGH reservoirs is hindered by significant technological limitations and high costs. Consequently, laboratory-synthesized gas hydrate-bearing sediment (HBS) samples are crucial for controlled research purposes and validating numerical simulation models and are used in the majority of research studies. With this in mind and considering the complexity of synthesizing HBS samples, this study comprehensively reviews different methods of synthesizing gas hydrates in porous media, including excess-gas, excess-water, dissolved-gas, spray, bubble injection, and hybrid techniques. Each method produces distinct hydrate morphologies (e.g., pore-filling, cementing, grain-coating, etc.) and saturation levels, with trade-offs in speed, uniformity, reproducibility, and ease of control. Furthermore, the current review details the synergic application of non-invasive characterization techniques, i.e., X-ray Computed Tomography (CT) and Nuclear Magnetic Resonance (NMR), in studying gas hydrates. CT provides high-resolution three-dimensional (3D) structural images of pore geometry and hydrate distribution, while NMR/MRI (Magnetic Resonance Imaging) quantifies fluid saturations and tracks hydrate formation/dissociation dynamics in real time. The synergistic use of CT and NMR offers a powerful multimodal approach, overcoming individual limitations such as CT's poor hydrate–water contrast detection and NMR's indirect hydrate inference, which could help in the sustainable synthesis of particular



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