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Influence of thermal stimulation on the methane hydrate dissociation in porous media under confined reservoir

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ABSTRACT

The kinetics of methane gas hydrate under confined environment in porous media have been studied for understanding the formation and dissociation behavior under this condition. We have developed a replica of natural hydrate-bearing atmosphere in a laboratory scale experimental set-up and examined the silica sand size effect on the formation and gas recovery in the presence of both pure water and seawater under confined reservoir conditions. Four sizes of silica sand particles were used in the present study (S1 (0.16 mm), S2 (0.46 mm), S3 (0.65 mm) and S4 (0.92 mm)). The formation experiments were done with 70% water saturation both for pure water and seawater. All these experiments were carried out at 277.15 K and 8 MPa. It is perceived that the gas consumption in the presence of smaller size sand particles is higher as compared to the larger size. The total consumption of methane gas during hydrate formation has been found to be less in the presence of seawater as compared to pure water. Subsequently, dissociation experiments have been carried out under confined reservoir conditions using thermal stimulation from 277.15 K to 303.15 K for 2 h. Gas recovery and dissociation rates are found to be higher in the smaller size silica sand bed in pure water as compared to bigger ones and seawater. Also, the maximum rate of dissociation was occurred at the near-equilibrium condition of pure methane hydrate system. Further insights into the dissociation behavior of methane hydrate under confined reservoir conditions have also been presented.

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1. Introduction

The world's energy demand and the consumption of fossil fuel are increasing day by day, while the conventional reserves are depleting at a startling rate. This makes the world move in a direction for searching unconventional fuel sources to satisfy the future energy needs. Among the unconventional energy resources, coal bed methane, shale gas, and gas hydrates, etc., have gained a great interest in the field of laboratory research and field investigations. In the hierarchy of potential future energy sources, gas hydrates stand at one of the top positions. Natural gas hydrates are crystalline, ice-like compounds of water and natural gas in which the latter occupies the cages formed by water molecules by hydrogen bonding (Sloan and Koh, 2008). In the presence of water at low temperature and elevated pressure, methane forms stable hydrates (Sloan and Koh, 2008). Hydrates have been one of the major challenges for flow assurance in upstream oil and gas

industry and several methods are being investigated to address the hydrate deposition issues (Sloan and Koh, 2008; Heidaryan et al., 2010). In addition, natural gas hydrates can be used for the storage and transportation of methane gas with or without the addition of promoters (Jarrahian and Heidaryan, 2014a; Avula et al., 2016; Sangwai and Oellrich, 2014).

Gas hydrates found to exist naturally at permafrost regions and offshore continental margins around the globe. Depending on the temperature and pressure, these natural gas hydrates occur at depth from 130 m to 2000 m below the ground at permafrost regions while in offshore continental margins, it is found to be existing at depths ranging from 800 m to 3000 m below the seabed (Sun et al., 2014; Vedachalam et al., 2015). Field investigations had established the existence of abundant quantity of gas hydrates worldwide. Moridis et al. (2011) mentioned that the United States of America itself have an estimated hydrate reserve of 3200–19,000 trillion m³. The natural gas stored in Indian Exclusive Economic Zone (EEZ) is expected to be approximately 1900 trillion cubic meters as natural gas hydrates (Sain et al., 2012). Till date, few field trials for the recovery of natural gas from hydrate have

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been performed with mixed success due to their occurrence in hostile environments like permafrost regions and deep subsea conditions (Vedachalam et al., 2015; Moridis et al., 2011; Sain et al., 2012; Ramesh et al., 2014).

Depressurization, thermal stimulation, and inhibitor injection are the potential methods employed in the production of natural gas from gas hydrate reservoirs. All these methods use the information on the phase stability of hydrate under complex environment (Nakano et al., 1999; Loh et al., 2012; Falser et al., 2012; Sami et al., 2013; Barmavath et al., 2014; Mimachi et al., 2016; Cao et al., 2016). In depressurization, due to the reduction of pressure, the state of the hydrate shifts below the equilibrium curve, while in thermal stimulation, it shifts to the right of the equilibrium curve. In both the cases, the near-hydrate zone conditions fall within the hydrate-unstable region thereby releasing methane gas. During inhibitor injection, the equilibrium curve shifts towards the low-pressure and high-temperature region and outside the hydrate stability zone releasing the methane hydrate. CO₂ sequestration is an alternate approach for the release of methane from its hydrate state (Kneafsey et al., 2007; Linga et al., 2009a; Wang et al., 2013; Falser et al., 2013; Mekala et al., 2014a, 2014b; Zhao et al., 2015a, 2015b; Song et al., 2015). Injection of CO₂ into methane hydrate bearing sediments is expected to replace methane out of structure-I hydrate, thereby releasing methane gas (Park et al., 2006; Sloan and Koh, 2008; Lee et al., 2015).

Typically, three types of sub-surface methane hydrate deposits have been classified. Moridis (2007) classified the gas hydrate reservoir as Class 1 reservoirs having overlying free gas layer, Class 2 reservoirs having overlying water saturated layer and Class 3 reservoirs having bounded two impermeable shale layers. Another classification includes: pore filling type, naturally fractured type and massive/nodule of hydrate deposits (Kurihara and Narita, 2011). In pore filling type of gas hydrate deposits, hydrate crystals are present in pore spaces of the rock (such as sandstone and carbonate) representing typical conventional oil and gas reservoir. In case of fractured type gas hydrate reservoirs, hydrate is accumulated in natural fractures of reservoir formations, while some hydrate deposits represent vast nodule of methane hydrate accumulated in the form of lumps in loose sand on the surface of seafloor (Kurihara and Narita, 2011). Different challenges are associated with the natural gas production from several of these hydrate reservoirs. Out of these, natural gas production from hydrate deposits in loose sand is challenging due to the hurdles associated with the containment of dissociated gas towards the production well (Ramesh et al., 2014). Recently, a feasibility study was performed for electro-thermal production method with a dome for the produced methane gas collection at subsurface under a confined reservoir, which can be a viable option to produce natural gas from such hydrate deposits. In case of hydrates in pore filling type rock matrix or Class 3 reservoirs, the in situ hydrate dissociation using warm water flooding had also worked out (Phirani and Mohanty, 2009). It is, therefore, necessary to understand how hydrate dissociates under confined environment. To make various production methodologies successful, laboratory based experimental studies on methane hydrate dissociation under confined environment are basic requirements which can provide insight into the behavior of reservoir.

A lot need to be understood on the dissociation mechanism of gas hydrate in complex porous media such as in loose sand. In order to dodge this hurdle, it is important to perform laboratory research to study the feasibility of extracting natural gas from the hydrate bearing sediments under simulated environment with closest approximation to the real field conditions (Ramesh et al., 2014; Vedachalam et al., 2015, 2016). For explicating the formation and dissociation characteristics of natural gas hydrates, artificial hydrate samples representing natural hydrates are synthesized in

laboratory scale (Kneafsey et al., 2007; Linga et al., 2009a; Mekala et al., 2014a; Chong et al., 2015, 2016). It has been found from field exploration that the sediments containing natural gas hydrates are found to be in clay to coarse-grained sand sediments of varying sizes (Waite et al., 2009; Chong et al., 2016). It has also found that the grain size of the porous media is an important factor affecting the formation and dissociation characteristics of hydrates. To understand this, a few studies on formation of methane and carbon dioxide hydrates were reported in an open literature using porous media, such as, glass beads, sand, activated carbon, etc. (Uchida et al., 2002; Riestenberg et al., 2003; Mekala et al., 2014a, 2014b; Wang et al., 2014, 2015, 2016; Chong et al., 2015, 2016). As hydrates occur in large quantity below the seabed, the research on the effect of seawater on the formation and dissociation of gas hydrates is very crucial, as the seawater is saline in nature. Various studies have been conducted to elucidate the hindering nature of salts as it is a thermodynamic inhibitor for the natural gas hydrate (Sami et al., 2013; Cao et al., 2016). Lee et al. (2015) reported that the CH₄ replacement by CO₂ is found to be reduced at higher concentration of NaCl. In their work, they used NaCl solutions having 0.5 wt% and 1.0 wt% concentrations in a stirred tank reactor. The limitation of this study from the production perspective is the use of stirred tank reactor instead of porous media. A study to understand the production scheme using dual wellbore, heating and depressurization were performed on separate wells (Loh et al., 2015). Experiments were conducted using seawater and distilled water. It was observed that the recovery factor was slightly lower in the case of seawater than distilled water. Most of the studies focused on the cumulative gas production without considering the kinetics of hydrate dissociation (Loh et al., 2015). In another study examining the formation and dissociation kinetics of methane, hydrates in seawater and silica sand, it was understood that there is a significant inhibition in the formation of methane hydrate in the presence of seawater than in pure water (Mekala et al., 2014a). However, the effect of sand particle size and confined reservoir conditions were not considered. Effect of different NaCl concentrations (0 wt%, 1.5 wt% and 3.0 wt%) on hydrate formation and dissociation has been carried out by Chong et al. (2015) and the result showed that the formation rate decreases and the dissociation rate increases as the NaCl concentration increases. Chong et al. (2016) had studied the effect of different sand sizes on the formation and decomposition of methane hydrate in pure water and found that the fine grain sand shown to increase the gas uptake in hydrate than the coarse grain. Results also demonstrated that the hydrate formation in the porous media was not uniform. While most of the studies in an open literature were focused on the studies involving pure water or in the simple NaCl salt solution for hydrate formation, the studies involving seawater, which contains a mixture of salts, and the size effect of porous medium need more investigations on the methane hydrate dissociation under confined reservoir to address some of the challenges associated with exploitation of hydrate resources (Barker and Gomez, 1989; Ji et al., 2001; Sung et al., 2002; Ahmadi et al., 2004; Phirani and Mohanty, 2009; Jiang et al., 2011; Ramesh et al., 2014; Bhade and Phirani, 2015a, 2015b).

Present study focuses on the kinetics of the methane hydrate formation and dissociation under a confined reservoir conditions in the presence of seawater and pure water. The effect of size of the porous medium (silica sand) has been investigated in detail on the gas hydrate dissociation profiles. The formation experiments were done at constant temperature of 277.15 K and an initial pressure of 8 MPa. Dissociation studies have been carried out under confined environment using thermal stimulation.

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