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Entropy generation analysis of hydrate dissociation by depressurization with horizontal well in different scales of hydrate reservoirs

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ABSTRACT

Based on the hydrate conditions of the South China Sea, hydrate samples were synthesized in the Cubic Hydrate Simulator (CHS) and the Pilot-Scale Hydrate Simulator (PHS), and hydrate dissociation experiments by depressurization with single horizontal well were carried out. In order to illuminate the characteristic of the irreversible energy loss during the gas production process in a large-scale hydrate simulator and a smaller hydrate simulator, the entropy generation model was established. Results show that the evolutions of the pressure, temperature, gas production, and water production during hydrate dissociation process with different scales of hydrate reservoir are similar. Moreover, entropy generation in the mixed gas release stage is the largest. In addition, in the dissociated gas release stage, the ratio of entropy generation decreases remarkably with the increase of the hydrate reservoir scale, and constant-pressure depressurization method is favorable for hydrate dissociation in a larger scale hydrate reservoir.

1. Introduction

With the development of the world economy, the energy production and consumption demands are growing continually. The BP Energy Outlook shows that the primary energy demand will increase 41% from 2012 to 2035 with the average annual growth rate of 1.5%, and China acts as the main growth driver [1]. The global energy structure is required to evolve toward a cleaning trend for addressing the global climate change concerns. Natural gas is the cleanest fossil energy due to the less carbon emission than coal and oil per equivalent amounts of energy consumption. This determines that natural gas plays an important strategic role in the future energy structure and some study shows that natural gas may catch up with oil and becoming the dominating fuel between 2020 and 2030 [2].

The unconventional natural gas resources play a significant role in the future energy supply, and natural gas hydrate is an important unconventional resource of nature gas for the vast amount of methane trapped in the global gas hydrate [3]. Natural gas hydrate is a crystalline solid compound which is formed by water and guest molecules under the conditions of high pressure and low temperature [4]. The guest molecules can be the hydrocarbon gases (methane, ethane, propane et al.) as well as non-hydrocarbon gases (nitrogen, carbon dioxide, hydrogen sulphide et al.). Generally, methane hydrate is in overwhelming abundance amongst other forms of gas hydrates. In nature, methane hydrate is widely distributed within the pores of the sediment under the permafrost regions or beneath the deep sea oceans. The methane density in the methane hydrate is larger than that in the rocks of the conventional natural gas reservoir. It is noted that approximately 170 m^3 of methane at the standard temperature and pressure conditions can be obtained from the dissociation of 1 m^3 of methane hydrate, and 0.81 m^3 of water is produced at the same time [5]. Although precise estimation of the gas hydrate reserves on the planet is uncertain, the common consensus is that the total amount of carbon content in the hydrate is twice as that of the combined carbon content of all other fossil energy [6]. Sustainable use of natural gas could stretch

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far into the future, even if only a relatively small amount of the explored methane hydrate can be exploited.

Unlike the conventional gas and oil, gas hydrate occurs as the form of solid in the earth. Hence, gas production from the methane hydrate reservoir necessitates hydrate dissociation in situ which the hydrate stable condition should be shifted to unstable status, and the gas can be collected from the hydrate accumulation [7]. Currently, the hydrate dissociation methods are mainly focus on depressurization [8–10], thermal stimulation [11–13], inhibitor injection [14–16], carbon dioxide replacement [17,18], and the combined use of these methods [19].

Establishing reliable and effective gas production technology from hydrate accumulations depends on the geotechnical characteristics of the hydrate reservoir. Currently, in view of the advantages of easy operation, cost effective, and no extra energy input, the depressurization method is regarded to be the most promising method amongst other production methods for the long-term gas production from marine hydrate accumulations [20]. The principle of hydrate dissociation by the depressurization method is lowering the reservoir pressure below the hydrate equilibrium pressure. The depressurization method has been successfully applied in the field tests from the permafrost regions in Mallik, Canada [21] and the oceanic sediments in the Nankai Trough, Japan [22]. On account of the characteristics of long term preparation, huge cost and time consuming process for the field tests, laboratory simulations of gas production from hydrate-bearing accumulations play key role on the current study of hydrate dissociation technology.

Heat transfer and mass transfer characteristics are crucial issues for gas production from hydrate reservoirs because hydrate dissociation is an endothermic process. A series of studies [23–26] on heat transfer characteristic of hydrate dissociation by depressurization have been carried out. These studies mainly focus on analyzing the heat balance and heat transfer processes (heat convection and heat conduction) in the gas production procedure. Namely, the principle of the first law of thermodynamics has been applied in these studies. However, there are irreversible heat losses not only in the phase change process of hydrate dissociation, but also in the gas migration and water production processes. Up to now, few literature about the thermodynamic features of hydrate dissociation using the second law of thermodynamics have been reported, and the characteristic of the irreversible heat loss during the gas production from hydrate reservoirs remain unclarified.

This work focuses on studying the thermodynamic features of gas production from different scales of hydrate reservoir by depressurization. The laboratory simulation and the entropy generation analysis are employed. The temperature and pressure conditions during the hydrate sample preparation and the hydrate dissociation processes are close to the local hydrate conditions in the South China Sea. Because of the advantages of the horizontal well production over the vertical well production for hydrate dissociation [27,28], the single horizontal well is performed as the production well in this work.

2. Experiments

2.1. Experimental apparatus

A cubic hydrate simulator (CHS) and a pilot-scale hydrate simulator (PHS) have been employed as the hydrate simulators in this work. The details of the CHS and the PHS have been introduced in the previous works [12]. The schematics of the CHS and PHS are similar, and the difference is that the PHS is placed in a cold room. As shown in Fig. 1, the high-pressure reactor made from stainless 316 is the core component. To guarantee the temperature stable in the reservoirs, the CHS is placed in a thermostat, and a water jacket which is performed as thermostat is around the PHS. Each the inlet and the outlet are installed with a pressure transducer for the sake of pressure measurement in the reservoir. Furthermore, a back-pressure regulator is placed at the outlet so as to control the production pressure. To record the amount of the pumped gas in the reservoir, a gas flow meter is placed at the inlet of the gas cylinder. Meanwhile, a gas flow meter is placed at the outlet value of the gas/liquid separator to measure the total amount of produced gas and the gas production rate. There is a vacuum pump which is placed at the bottom of the high-pressure reactor to remove the residual gas in the reservoir before hydrate formation. The water employed for hydrate formation is injected by a metering pump. In addition, in order to measure the amount of water production during the gas production process, a balance is situated after the gas/liquid separator. As depicted in Fig. 2a, the inner shape of the PHS is cylindrical.

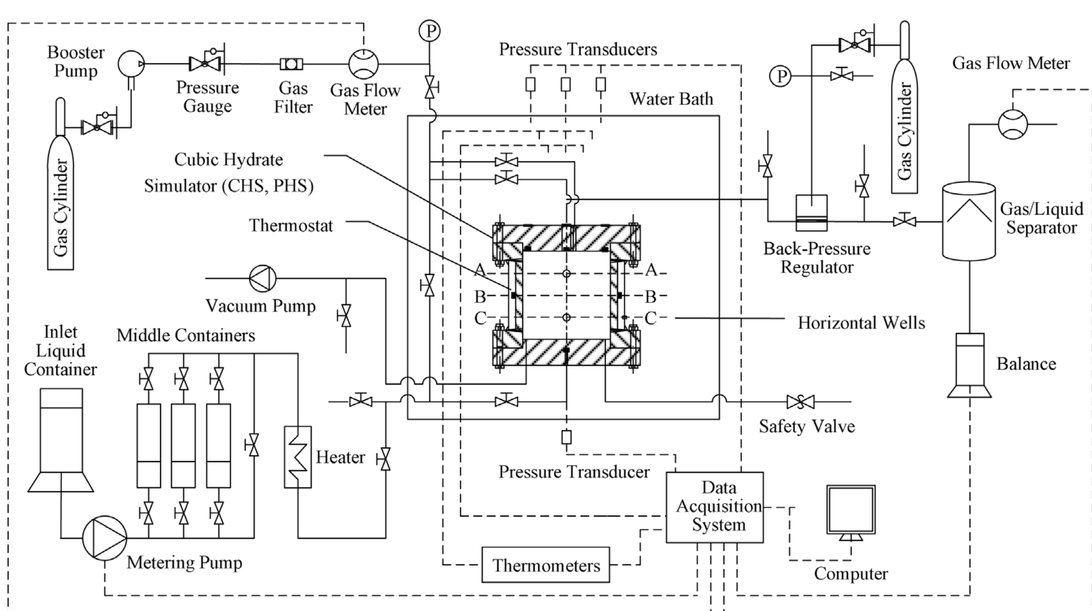

Fig. 1. Schematic of the experimental apparatus.