



Energy and entropy analyses of hydrate dissociation in different scales of hydrate simulator



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ABSTRACT

To investigate the effect of the reservoir scale on hydrate dissociation by depressurization in conjunction with warm water stimulation with dual horizontal wells, experiments of hydrate dissociation by such method have been carried out in CHS (Cubic Hydrate Simulator) and PHS (Pilot-scale Hydrate Simulator). The results show that there is little difference of temperature variation during the depressurizing stage with different scales of hydrate simulator. However, during the constant-pressure stage (the injection stage), the difference is obvious, and the heat transfer rate in the PHS is faster than that in the CHS. Additionally, the system entropy production during the injection stage is the largest, implying that the injection stage is the main source of energy consumption. Moreover, both the ratio of the amount of the dissociated gas in the PHS to that in the CHS and the ratio of the entropy production for hydrate dissociation with the PHS to that with the CHS approximately equal to the volume ratio of the PHS to the CHS.

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1. Introduction

Natural gas hydrate is widely distributed in the permafrost regions and the offshore oceanic regions, where the local environments of high pressure and low temperature are satisfied. In nature, gas hydrate exists as an ice-like solid in which the guest molecule (mainly methane) is encapsulated in the hydrogen-bonding cages comprised by water molecules [1,2]. Accurate estimation of the amount of gas hydrate on the earth is challenging, and the common perception is that the total carbon content in gas hydrate is more than twice as much as that in all of the conventional fossil fuels [3]. If 1 cubic meter of gas hydrate is dissociated at standard pressure and temperature, 164 m³ of gas and 0.8 m³ of water can be produced. The previous studies [4,5] indicate that the energy density of methane hydrate is 2–5 times larger than that of the conventional natural gas, and 10 times larger than the other kinds of unconventional gas sources, such

as shale gas and coal bed gas. Generally, methane hydrate is considered to be a potential energy resource on account of the huge gas reserves in hydrate resource and the high density of methane hydrate [6,7]. Moreover, gas hydrate has been widely applied in the process of carbon dioxide capture [8–10], hydrogen storage [11] and flow assurance of the seabed pipeline [12].

Gas hydrate is dissociated when the stable condition of pressure and temperature is disturbed [13]. Up to now, the conventional research methods for hydrate dissociation are depressurization [14–18], thermal stimulation [19–22], inhibitor injection [23–25], and carbon dioxide replacement [26]. From the perspectives of high energy ratio, high production efficiency, and the avoidance of ice blockage and hydrate re-formation, the combination of depressurization and thermal stimulation is regarded to be a profitable method for hydrate dissociation [27–29]. Due to the huge energy loss with the increase of water injection temperature, Feng et al. [30] reported that high temperature (beyond 40 °C) injection was not economic for hydrate dissociation, and they further indicated [31] that the optimal injected temperature for hydrate dissociation in a 5.83 L cubic hydrate simulator was 38–39 °C by using the evaluation methods of entropy production minimization and energy ratio maximization. The hydrate dissociation behavior and the production performance of the hydrate reservoir are strongly

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affected by the scale of hydrate reservoir. The numerical research of Tang et al. [32] showed that the controlling mechanism of hydrate dissociation in the reservoir of small scale is kinetic-controlled. Whereas the controlling factor of hydrate dissociation in large scale hydrate reservoir is fluid flow. In addition, the analytical modeling of Wang et al. [33] also indicates that hydrate dissociation in the large scale hydrate reservoir is strongly dependent on the characteristics of heat transfer, mass transfer, and fluid flow. Both the experimental and numerical analyses of Li et al. [34] showed that the kinetic limitation was weak for hydrate dissociation by depressurization in a 117.8 L hydrate simulator. In general, the hydrate reservoir scale is an important factor which affects gas production from the hydrate-bearing reservoir. Up to now, the investigation of reservoir scale for hydrate dissociation mainly focuses on the vertical well configuration and the behaviors of gas and water production. There is short of the investigation of the effect of reservoir scale on horizontal well configuration and the optimization of the operating condition during hydrate dissociation. Therefore, the research of the effect of reservoir scale on the optimization of the operating condition for hydrate dissociation, especially with the horizontal well system, is desperately needed.

Hydrate dissociation is an irreversible process during the laboratory-scale experiment. For the irreversible process, entropy analysis, which is the application of the second law of thermodynamics, has been considered as an efficient way that shows the sources of energy losses and what modifications should be conducted to increase the energy efficiency [35]. Entropy generation is proportional to the lost work in an irreversible process, and the entropy generation is contribute to explain the optimal conditions for energy losses [36]. The method of entropy generation minimization which means the minimization of energy consumption, has been widely used in the optimal processes of the co-generation plant [37], the distillation [38], the heat convection in porous media [39], the heat engines [40], and so on. Based on the minimum entropy generation theory, Feng et al. [31] has obtained the optimal temperature range for hydrate dissociation in a 5.83 L reactor with the dual horizontal wells. However, there is lack of the evolution of the entropy generation with different scales of reservoir.

The main purposes of this work are the investigations of the evolutions of hydrate dissociation behaviors and entropy production under different scales of hydrate reservoir. Hydrate samples were synthesized in a 5.83 L CHS (Cubic Hydrate Simulator) and a 117.80 L PHS (Pilot-scale Hydrate Simulator). Considering the advantage of horizontal well pattern over the vertical well pattern [41,42], the dual horizontal wells were set as the production scenario. The pressure and temperature condition of hydrate formation and dissociation were originated from the exploration data of hydrate accumulation in the South China Sea. The behaviors of gas production, water production, hydrate dissociation, and entropy production in different scales of hydrate reservoir were obtained.

2. Experimental apparatus and process

2.1. Experimental apparatus

The schematic of the two apparatus are shown in Fig. 1. The CHS is a cubic hydrate simulator with the side length of 180.00 mm. The diameter of the PHS is 500.00 mm and the height of the PHS is 600.00 mm. As shown in Table 1, the inner volume of the CHS and the PHS is 5.83 and 117.80 L, respectively. The components of the two apparatus are similar. The differences are that the volume of the PHS is almost 20 times larger than that of the CHS, and the PHS is placed in a cold room. As shown in Fig. 1, the high pressure reactor made from stainless steel 316 is the core of the apparatus. An inlet pressure transducer and an outlet pressure transducer are placed in the bottom and top of the reactor, respectively. The CHS is immersed in a water bath ($-15\text{--}30\text{ }^{\circ}\text{C}$, $\pm 0.1\text{ }^{\circ}\text{C}$) to ensure the

Table 1
Parameters of methane hydrate formation in the CHS and PHS.

	CHS	PHS
Inner Volume (L)	5.83	117.80
Pore Volume (mL)	2752.00	51,360.00
Bath Temperature (k)	281.15	281.15
P_0 (MPa)	20.05	19.63
P_{end} (MPa)	13.400	13.70
T_{end} (k)	281.85	281.87

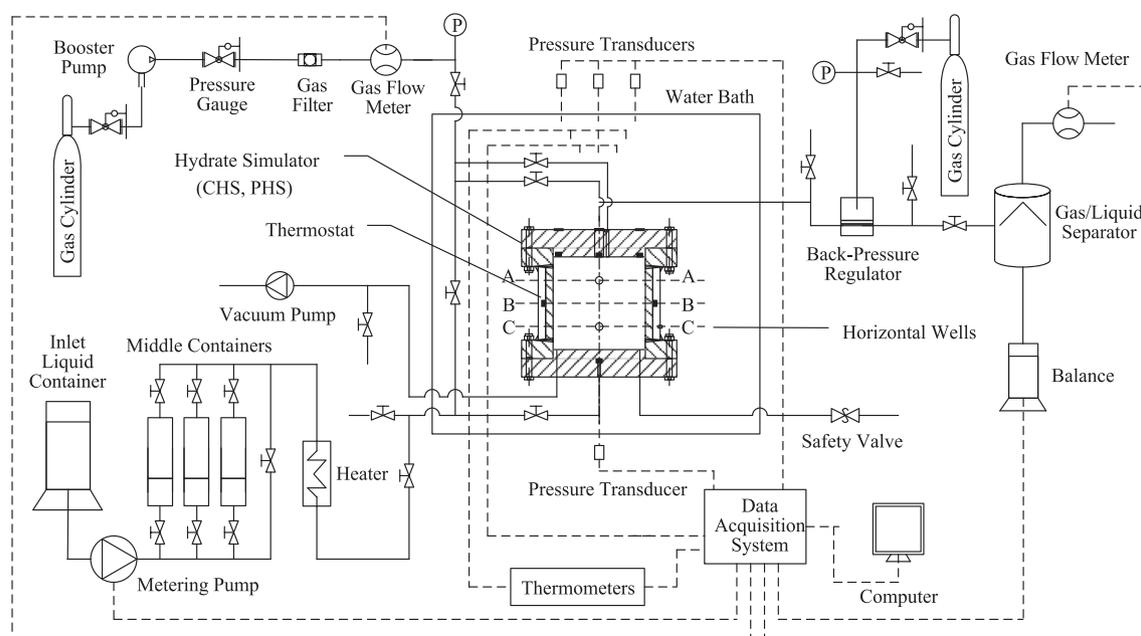


Fig. 1. Schematic of the CHS and PHS.

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