EXPERIMENTAL STUDY OF INFLUENCE FACTORS OF HOT-BRINE STIMULATION FOR DISSOCIATION OF NGH IN POROUS MEDIUM

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ABSTRACT
A new one-dimensional experimental system for modeling natural gas hydrate (NGH) development is designed, which is used to study the formation and dissociation process of NGH. Modeling marine geological environment, NGH is formed in the sand-packing tube, and then hot-brine is injected to the tube to study the thermal dissociation characteristics, and the injection parameters which influence the thermal dissociation behavior and energy efficiency are analyzed. The temperatures of the injected hot-brine are 60°C, 80°C and 100°C respectively, the injection rates are 12ml/min, 15ml/min and 18ml/min respectively, and the injection time is 240min maximally. The experimental results show that: for the same hot-brine injection rate, the higher the temperature is, the larger releasing rate of gas from hydrate dissociation is, the lower energy efficiency becomes. Moreover, for the same temperature of injected hot-brine, the higher the injection rate is, the larger releasing rate of gas from hydrate dissociation is, the lower energy efficiency becomes. As the injection time extends, the energy efficiency of thermal stimulation decreases gradually. Therefore, “hot brine slug + water flooding at normal temperature”, or combination of the thermal method and depressurization are proposed, which can improve the economic efficiency to develop NGH reservoirs.

Keywords: natural gas hydrate, NGH formation, thermal dissociation of NGH, hot-brine temperature, injection rate

NOMENCLATURE

\( C_w \) specific heat of water \( [J/(g \cdot ^\circ C)] \)

\( Q_{ou} \) heat of methane gas released \( [J] \)

\( Q_{in} \) the heat of injected hot brine \( [J] \)

\( V_g \) the volume of methane released from hydrate decomposition \( [cm^3] \)

\( V_w \) the volume of injected water \( [cm^3] \)

\( \Delta h_g \) the heat of combustion of methane \( [J/cm^3] \)

\( \rho_w \) the density of water \( [g/cm^3] \)

\( \theta_w \) the injection temperature of hot brine \( [^\circ C] \)

\( \theta_0 \) room temperature \( [^\circ C] \)

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INTRODUCTION

Natural gas hydrate, found in marine and permafrost in recent years, is a kind of nonpolluting and high-quality new energy resource. It is widely distributed with huge reserves and it will become the most important human energy resource in 21st century [1]. The studies associated with the properties and the developing technologies of NGH have attracted great attentions of the governments around the world.

The exploit methods of NGH that have been proposed include: thermal stimulation, depressurization, inhibitor injection [2], CO2 replacement method [3-5], mining method [6] and drilling incline wells, most of them are conceptual. As for the actual hydrate reservoirs, the only case is Messoyakha Gas Field of Soviet Union, which is exploited by depressurization and inhibitor injection methods for almost 20 years [7, 8]. In addition, production test [9-11] of depressurization and thermal method have been successfully conducted on Mallik field, Northwest Territories of Canada, in March 2002. Among the methods of depressurization, thermal stimulation and inhibitor injection which are practically used, depressurization costs less but is restricted by initial temperature and permeability of gas hydrate reservoir; thermal method is more applicable but it has great heat loss; inhibitor injection is associated with high cost. It is considered that depressurization, thermal stimulation and the combination of the two methods are likely to become the effective way to exploit the NGH on a large scale in the future.

At present, most researches on the properties of NGH and production simulations are investigated through laboratory experiment. Yousif and Sloan et al. [12,13] have conducted the experiment of NGH formation and depressurization production using the Berea core. The experiment of NGH decomposition by injection hot brine was conducted by Kamath et al. [14]. The experimental study on NGH formation and depressurization production in sediment has been done by Kono et al. [15]. Baldwin et al. [16] developed a method, using magnetic resonance imaging (MRI), to monitor the formation and dissociation properties of pure hydrate and hydrate in porous media. Wonmo S et al. [17, 18] have done experimental study on NGH phase equilibrium and dissociation by depressurization, methanol injection and thermal method using the Berea core. In china, Tang Liangguang et al. [19] Hao Yongmao et al. [20] and Wan Lihua et al. [21] have done the experimental study on dissociation of NGH by thermal stimulation. Zhang Weidong et al. [22] analyzed the energy efficiency during the process of thermal stimulation and considered that most energy is consumed by warming of non-hydrate. It should be point out that: the experimental studies mentioned above only discussed the dissociation dynamic and energy efficiency preliminarily; however, the injection parameters which influence the thermal stimulation of NGH have not been researched systematically. So we mainly study the injection parameters, such as the hot-brine injection temperature, injection rate and injection time, which influence on the dissociation dynamic and energy efficiency during the dissociation process of NGH by injection hot-brine, thereby give a guide to the further study of thermal dissociation experiment and numerical simulation.

EXPERIMENTAL

An experiment equipment of NGH exploitation simulation has been designed according to properties of NGH. The experimental system includes 7 modules, including water supplying, gas supplying, formation and decomposition modeling, environment simulating, backpressure regulating, parameter (pressure, temperature and flow flux) measuring and data collecting. The formation and decomposition modeling is the heart of the experimental system, whose principal part is the
one dimensional high-pressure sand-packed tube. The tube is stainless steel with pressure-resisting values of 25 MPa and working pressure of 20 MPa. The tube size is 80 mm in inner diameter and 800 mm in inner axial length. Along the one-dimensional flow direction of the tube, 11 sets of pressures and temperature probes are arranged uniformly in order to monitor the pressure and temperature along the axis during the process of NGH formation and decomposition. Fig. 1 shows the main flowchart of this experiment system.

![Figure 1. The main flowchart of experimental system](image)

The natural marine sand is used for the experiment, which particle diameters are $200 \mu m$ to $450 \mu m$. The porosity of the sand-packed tube is 34.2% and the permeability measured by water is $1.42 \mu m^2$. The water used is the synthetic brine with the mass concentration of 2.0% and the NaCl purity $\geq 99.5%$. The methane gas is in 99.9 % purity.

The procedures for the formation and decomposition of NGH are as follows:

1. Isovolumetric formation of NGH. Firstly, inject water and methane gas that is predetermined into the sand-packed tube until the pressure increases to about 8~9MPa. Then the tube is sealed and the environmental temperature is decreased to 2°C, waiting isovolumetric formation of NGH. At the same time, collect pressure and temperature data of each measuring point in real time to monitor the formation process of NGH. When the system pressure stops decreasing with time, the isovolumetric formation of NGH is considered completed.

2. Decomposition of NGH by injecting hot brine: After the formation of NGH, set the backpressure equal to the pressure of the system. Then inject hot brine into the sand-packed tube to dissociate NGH, and the temperature of hot brine, injection rate and injection time is pre-designed. The pressure, temperature, water and gas production rate at the outlet are recorded in order to monitor the process of decomposition. After the dissociation of NGH by hot brine injection, decrease the system pressure in order to release the remainder gas in the tube.

The purpose of the experiment is to study the effects of different injection parameters on NGH decomposition. Therefore, the pre-condition of hydrate formation should be the same. In our experiments, the saturation of NGH is about 0.11, the pressure is 3.3-3.6MPa and the temperature is 2.1-2.4 °C. The injection parameters which we studied include the temperature of hot brine, the injection rate and injection time (injection heat).

**RESULTS AND DISCUSSION**

**The influence of hot brine temperature**

Choose the following experiments to analyze the influence of hot brine temperature on NGH decomposition. In this group of experiments, the hot brine injection rate is 18ml/min, injection time is 220min and injection temperature of hot brine is 60℃, 80℃, 100℃ respectively.

**The influence on gas production rate**

The gas production rate of NGH decomposition at different temperature of hot brine injection is shown in Figure 2.
It is shown that the gas production curves have the same characteristics at different temperature injection of hot brine. It can be divided into three processes: the release of the free gas in the tube (the first peak in gas production curve), gas release from hydrate decomposition by thermal stimulation (the stable gas production of intermediate stage) and release of the remainder gas in the tube (the last peak in gas production curve). In the first process, the higher the temperature of injection hot brine is, the higher the gas production rate of free gas release is, which is due to the thermal expansion of free gas in the sand-packed tube. In the stage of hydrate decomposition, the higher the temperature of injection hot brine is, the higher the gas production peak becomes, and the earlier the gas production peak appears. But the accumulation of gas production in this stage is nearly identical due to the same saturation of NGH in the tube. In the stage of gas production by depressurization, the temperature also plays an important role on the gas production rate. The higher the temperature, the higher the gas production rate, because the temperature of the sand-packed tube is still high after hot brine injection.

The influence on temperature field
1# to 11# temperature probes are distributed evenly along the sand-packed tube from inlet to outlet. Choose the 6# point which is distributed in the middle of the tube to analyze the influence on temperature field. The temperature vs. time of the 6# measuring point at different temperature of injection hot brine is shown in Figure 3.

The influence on energy efficiency
It is an endothermic process for the decomposition of NGH. However, methane gas released from NGH contains heat. The energy efficiency is defined as the ratio of the heat of the methane gas released to the injection heat, namely:

$$\lambda = \frac{Q_{out}}{Q_{in}} = \frac{V_g \Delta h}{C_w V_w \rho_w \left(\theta_w - \theta_0\right)}$$ (1)
The energy efficiency at different injection temperature of hot brine is shown in Figure 4. It should be pointed out that the heat loss before the hot brine flow into the sand-packed tube is ignored. It can be seen that for the same injection rate of hot brine, the higher the injection temperature is, the lower energy efficiency becomes. Because only a little injection heat is used to dissociate the hydrate, a lot of heat is lost which is used for heating quartz sand, water, CH4 gases and experiment surroundings. On the condition that the NGH can be decomposed completely, the energy loss increases as the injection temperature increases. Therefore, more effective thermal technology should be used in order to reduce the heat loss and improve the energy efficiency.

Figure 4. the energy efficiency at different injection temperature of hot brine

The influence of hot brine injection rate
Choose the following experiments to analyze the influence of hot brine injection rate on NGH decomposition. In this group of experiments, the injection temperature of hot brine is 100℃, injection time is 220min and the injection rate of hot brine is 18ml/min、15ml/min、12ml/min respectively.

The influence on gas production rate
Figure 5 shows the gas production rate of NGH decomposition at different injection rate of hot brine.

Figure 5. gas production curve at different injection rate of hot brine

Same as the influence of the injection temperature, the gas production curves can be divided into three stages again. The higher the injection rate of hot brine is, the higher the gas production rate of NGH decomposition becomes, and the earlier the gas production peak reaches. This shows that increasing the injection rate of hot brine can accelerate the decomposition rate of NGH.

The influence on temperature field
6# measuring point is chosen again to analyze the influence of hot brine injection rate on temperature filed, which is shown in figure 6.

Figure 6. the temperature vs. time at different injection rate of hot brine

The influence of injection rate on temperature filed is similar to that of the injection temperature. The
higher the injection rate of hot brine is, the earlier the temperature begins to rise at the same measuring point, and the higher the temperature reaches.

**The influence on energy efficiency**

Figure 7 shows the energy efficiency at different injection rate of hot brine. It can be seen that the energy efficiency decreases as the injection rate increases for the same injection temperature of hot brine. By increasing the injection rate of hot brine, the decomposition of NGH can be accelerated; it is helpful to the release of CH$_4$, so the total heat of CH$_4$ generated increases. However, increasing the injection rate of hot brine means injecting much more quantity of heat, so the energy efficiency decreases ultimately. At the same time, by comparing Figure 7 with Figure 4, we can see that for the same initial condition of NGH, within the range of experimental study, the influence of injection temperature on the energy efficiency is far greater than that of injection rate of hot brine.

![Figure 7. the energy efficiency at different injection rate of hot brine](image)

**The influence of injection time**

At the same injection temperature and injection rate of hot brine, different injection time means different injection of heat fluxes in fact. For example, the injection temperature of hot brine is 60°C, the injection rate of hot brine is 18ml/min, select the injection time of 25, 50, 75, 100, 125, 150, 175, 200, 220min to analyze the energy efficiency. Figure 8 shows the energy efficiency at different times.

![Figure 8. the energy efficiency vs. time](image)

It can be seen that the energy efficiency decreases as the injection time extend during the process of injecting hot brine. This is mainly due to the low saturation of NGH in the sand-packed tube and the relatively high heat loss in our experiment. During the thermal stimulation of NGH dissociation, when the gas production rate decreases to a certain degree, it is un-economic to inject hot brine continuously. Therefore, “hot brine slug + water flooding at normal temperature”, or combination of the thermal method and depressurization are proposed, which can improve the economic efficiency to develop NGH reservoirs.

**CONCLUSIONS AND SUGGESTIONS**

(1)NGH can be decomposed through thermal stimulation by injecting hot brine. In our experiment, the higher the injection temperature and injection rate is, the faster the decomposition rate of NGH becomes and the higher the gas production rate reaches, but the lower the energy efficiency becomes;
(2)Within the range of our experimental research, the influence of injecting temperature of hot brine on the energy efficiency is far greater than that of the injecting rate;
(3) The energy efficiency decreases as the injection time extend during the process of injecting hot brine in our experiments;
(4) During the process of injection hot brine, when the gas production rate decreases to a certain degree, it is un-economic to inject hot brine continuously. Therefore, “hot brine slug + water flooding at normal temperature”, or combination of the thermal method and depressurization are proposed, which can improve the economic efficiency to develop NGH reservoirs.

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REFERENCE


