

LARGE-SCALE EXPERIMENTAL INVESTIGATION OF INFLUENCE OF DEPRESSURIZATION RATE ON HYDRATE DISSOCIATION IN SANDY SEDIMENT

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ABSTRACT

Due to the vast amount of recoverable natural gas predicated (~3,000 TCM) in natural gas hydrate on earth, natural gas hydrate has the potential to become the next generation of unconventional source of fuel. Recently years, laboratory researches are still underway to advance our understanding of the theory and technology for natural gas hydrate exploitation. The Pilot-Scale Hydrate Simulator (PHS), a three-dimensional 117.8 L pressure vessel, was applied to study the methane hydrate dissociation using depressurization with different depressurization rates in the sandy sediment. The volume of the vessel is big enough to simulate the field-scale gas production from hydrate reservoir. The production behaviors and heat transfer characteristics during hydrate dissociation in sandy sediments with different depressurization rates were compared and investigated. The experimental results indicate the influence of depressurization rate on hydrate dissociation using depressurization method. The lower depressurization rate leads to the larger amount of hydrate dissociation during depressurizing stage, because the fluid flows in this stage enhance the heat convection in the sediment causing a higher heat transfer rate from surroundings. In addition, the lower depressurization rate causes the lower water production rate, which benefits for the gas production from hydrate reservoir. On the other hand, fast pressure dropping may lead to ice formation and secondary hydrate formation in the pipeline. However, the higher depressurizing rate leads to a higher gas production rate in the depressurizing stage. Therefore, an optimized depressurizing rate for hydrate dissociation with the highest energy efficiency is performed.

Keywords: Nature gas hydrate; Depressurization rate; Sandy sediment; Large-scale experiment; Heat and mass transfer

1. INTRODUCTION

Due to the increase of the energy demand, it is imperative to develop an alternative energy source to solve energy shortage. Natural Gas Hydrate (NGH) can be regarded as alternative energy source in future due to huge reserves of methane gas trapped in hydrate bearing formations. Although the precise estimation of methane hydrate all over the world is uncertain, and the estimation vary from 2.8×10^{15} to 8.0×10^{18} m³ [1, 2]. The energy reserves in gas hydrate is considered as huge. The common sense can be expressed that gas hydrates contain most of the methane on earth and account for roughly a third of the mobile organic carbon all over the world [3]. Huge reserves and worldwide distribution are the great advantages of methane hydrate, which makes methane hydrate the most important substitute energy resource for petroleum, coal, nature gas in 21th century[4].

NGH is an ice-like solid compound which is stabilized when water and guest molecules contact in the conditions of high pressure and low temperature, such as the marine deposit and the permafrost regions [5-7]. Methane, ethane, propane, nitrogen, hydrogen, and etc., are regarded as the guest molecules trapped in the cage constituted by water molecules. Methane is the most common guest gas in nature. It is commonly recognized that 1 m³ of hydrate can release 160 m³ of natural gas [8].

Selection and peer-review under responsibility of the scientific committee of the 11th Int. Conf. on Applied Energy (ICAE2019).

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Unlike the conventional gas and oil reserves, recovering natural gas from the NGH refers to hydrate dissociation process. This is a complex process which combined multi-phase change, heat transfer and mass transfer. Hydrate dissociation from in-situ situation should break the stable pressure-temperature condition for NGH, and gas releasing from the NGH must overcome the Van der Waals force between the water molecule and guest molecule[9].

During the past four decades, over 230 natural gas hydrate deposits have been found in our planet. Depressurization [10-13], thermal stimulation [14, 15], chemical injection [16, 17], and the combined application have been applied and investigated for hydrate destabilization [18, 19]. The models of hydrate dissociation using different methods have been reported [20, 21]. If only 17 to 20% of this resource can be exploited, NGH can be a sufficient supply of energy source for at least 200 years [22]. Field test of NGH exploitation not only plays important role in improving production technology but also in assessing environmental and security effects. Seven field tests of gas production from hydrate deposits have been conducted around the world since 2002. Four filed tests have been carried out in the permafrost region, and three tests have been performed in the marine environment.

According to the laboratory studies and field programs, depressurization method has been considered as the most cost-effective and practical way to dissociate gas hydrates [2]. Because the hydrate dissociation is an endothermic (heat absorbing) process, the dissociation-inducing depressurization leads to the decrease of reservoir temperature. However, when the reservoir temperature decreases to the hydrate stability temperature at the production pressure, no more sensible heat in the sediment can be absorbed for hydrate dissociation. Afterwards, the heat consumption for hydrate dissociation is supplied by heat transfer from surroundings. Thus, the rates of hydrate dissociation decrease obviously. This phenomenon has been investigated experimentally and also found in field test at the Shenhu area in South China Sea.

In this work, the Pilot-Scale Hydrate Simulator (PHS), with an inner volume of 117.8 L, was applied to investigate gas recovery approach from hydrate reservoir. In order to evaluate the influence of depressurization rate on hydrate dissociation, three different rates for gas recovery from hydrate reservoir were performed in the PHS. The production behaviors

and heat transfer characteristics during hydrate dissociation in sandy sediments by different depressurization rates were compared and investigated.

2. EXPERIMENTS

2.1 Experimental Apparatus

Experimental system consists of 6 primary subsystems: (A) a stainless steel high-pressure reactor is the core component; (B) an injection system including the gas pump, the gas flow meter, and the metering pump for water; (C) a production control system which comprises the gas/liquid separator, the back-pressure regulator, the gas flow meter and balance; (D) an ambient temperature controlling system; (E) a data acquisition system collecting the experimental data of pressure, temperature as well as gas and water flow parameters, and (F) measuring units. The experimental system schematic is given in Fig. 1. The experimental system has been also described in all details in the previous study [10]. The apparatus is named as the "Pilot-scale Hydrate Simulator" (PHS). The effective volume of the PHS is 117.8 L, and it can withstand high pressure as high as 30.0 MPa. The inner of the PHS is cylindrical with the inner diameter of 0.50 m and the inner height of 0.60 m. The whole experimental system is placed in an air bath room. The PHS is also surrounded by a water bath to keep the temperature stable. The ambient temperature is controlled by the water jacket and the air bath.

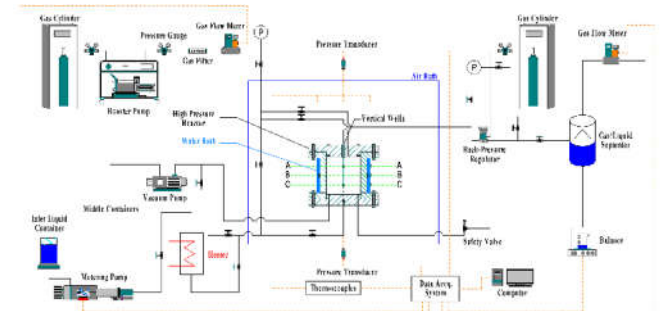


Fig.1. Schematic of apparatus

Fig. 1 also shows the inner structure of the PHS as well as the arrangements of the wells. As shown, three equidistant layers (Layer A-A, Layer B-B, and Layer C-C) divide the inner of the PHS into four regions. Thermalcouple sensors are distributed in each horizontal layer as a matrix, and the number of the thermal couples on each row and column is 7. Therefore, there are a total of 49 thermalcouple sensors on each layer. Thus, the 147 thermalcouple sensors are placed in the sediment. For example, T43A represent the 43rd thermal couple on Layer A-A. In this

work, a center vertical well was employed for fluid production. As displayed in Fig. 1, the production well W_{pro} is located at the center of the top layer in the PHS, which is applied for releasing fluids during the experiments.

2.2 Experimental procedure

Quartz sand with particle sizes of 300-450 μm and density of 2.6 g/cm^3 was filled in the PHS and acted as porous media before hydrate formation. After sand filling, the porosity and the permeability of the sediment are approximately 46% and 35 Darcy, respectively. In this work, water-saturated hydrate-bearing samples are synthesized for the experiments. In this work, water-saturated hydrate-bearing sample means that the final gas saturation in the sand sample at the end of the multi-step water injection method was lower than 5%. Water injection was conducted until the majority of the methane in the PHS was converted into hydrate. The initial system pressure also was 13.50 MPa. The final gas/water/hydrate saturation after hydrate formation can be calculated. Since the gas saturation is very low (below 5%), we refer to this experiment as “water-saturated”.

After hydrate formation, hydrate decomposition experiments can be performed. Hydrate decomposition is characterized by two stages: (1) the depressurizing (DP) stage, during which the pressure in the PHS was decreased from the initial pressure (13.50 MPa) to the production pressure (4.50 MPa). During this stage, the outlet of the production well (W_{pro}) was opened for gas and water production, and the pressure in the reactor was controlled by the back-pressure reactor. (2) The constant-pressure (CP) stage, in which the pressure in the reactor was maintained at the constant pressure (4.50 MPa) until the end of the experiment. When no more gas was produced out from the PHS, it can be regarded that the hydrate dissociation experiment was completed.

After the completion of hydrate dissociation, the residual gas was released and the pressure in the PHS was gradually decreased to 0. During the hydrate dissociation, the experimental data of pressures, temperatures, volume of gas production, and mass of water production were recorded in real time.

3. RESULTS AND DISCUSSIONS

Fig. 2 shows the pressure change during hydrate dissociation by depressurization with different depressurizing rates. As seen in this figure, the duration of the DP stage for Runs 1-3 are 100 min, 200 min, and

300 min, respectively. In the CP stages, the pressures for Runs 1-3 are kept at 4.5 MPa until the end of hydrate dissociation. Meanwhile, the total duration for the experiment with a lower depressurizing rate is shorten.

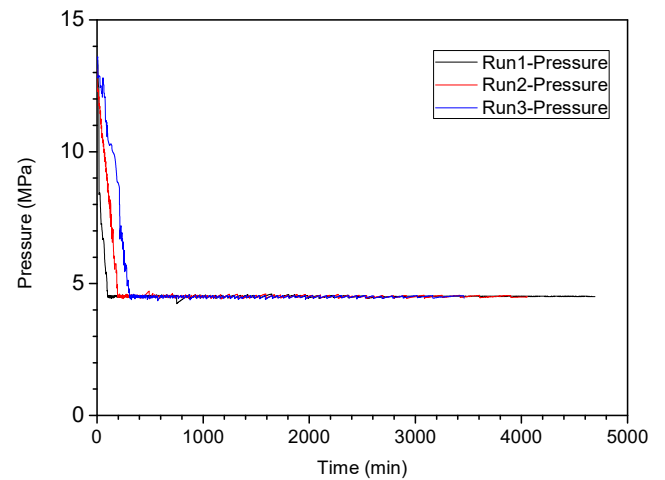


Fig.2. Pressure change during hydrate dissociation by depressurization with different depressurizing rates

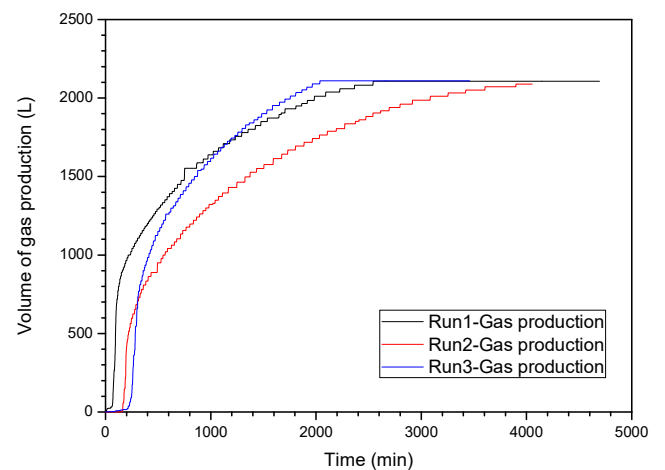


Fig.3. Volumes of gas production during hydrate dissociation by depressurization with different depressurizing rates

Fig. 3 and Fig. 4 show the volumes of gas production and water production during hydrate dissociation by depressurization with different depressurizing rates. As seen in these figures. The lower depressurization rate leads to the larger amount of hydrate dissociation during depressurizing stage, because the fluid flows in this stage enhance the heat convection in the sediment causing a higher heat transfer rate from surroundings. In addition, the lower depressurization rate causes the lower water production rate, which benefits for the gas production from hydrate reservoir. On the other hand, fast pressure dropping may lead to ice formation and secondary hydrate formation in the pipeline. However, the higher

depressurizing rate leads to a higher gas production rate in the depressurizing stage.

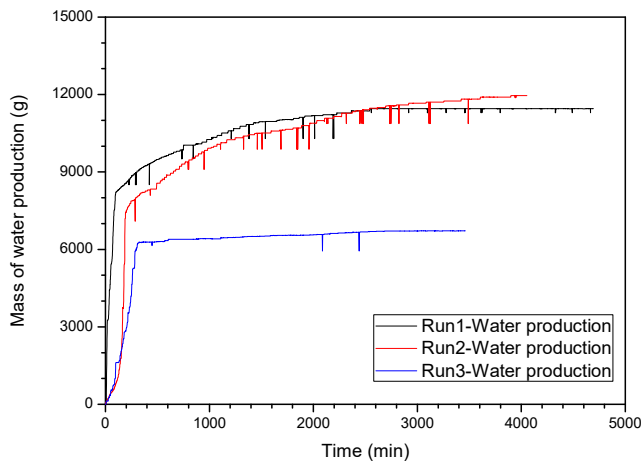


Fig.4. Mass of water production during hydrate dissociation by depressurization with different depressurizing rates

4. CONCLUSIONS

The Pilot-Scale Hydrate Simulator (PHS), a three-dimensional 117.8 L pressure vessel, was applied to study the methane hydrate dissociation using depressurization with different depressurization rates in the sandy sediment in this work. The experimental results indicate the influence of depressurization rate on hydrate dissociation using depressurization method. The lower depressurization rate leads to the larger amount of hydrate dissociation during depressurizing stage, because the fluid flows in this stage enhance the heat convection in the sediment causing a higher heat transfer rate from surroundings. In addition, the lower depressurization rate causes the lower water production rate, which benefits for the gas production from hydrate reservoir. On the other hand, fast pressure dropping may lead to ice formation and secondary hydrate formation in the pipeline. However, the higher depressurizing rate leads to a higher gas production rate in the depressurizing stage. Therefore, an optimized depressurizing rate for hydrate dissociation.

ACKNOWLEDGEMENT

This work is supported by National Natural Science Foundation of China (51676190), National Key Research and Development Plan of China (2016YFC0304002, 2017YFC0307306), Youth Science and Technology Innovation Talent of Guangdong (2016TQ03Z862), Natural Science Foundation of Guangdong (2017A030313313).

REFERENCE

- [1] Seol J, Lee H. Korean J Chem Eng. 2013;30:771-86.
- [2] Milkov AV. Earth-Sci Rev. 2004;66:183-97.
- [3] Maddox TM, Ross C, Ho PM, Magid D, Rumsfeld JS. BMC Cardiovasc Disor. 2009;9:-.
- [4] Chong ZR, Yang SHB, Babu P, Linga P, Li XS. Appl Energ. 2016;162:1633-52.
- [5] Moridis GJ, Collett TS, Boswell R, Kurihara M, Reagan MT, Koh C, et al. Spe Reserv Eval Eng. 2009;12:745-71.
- [6] Boswell R. Science. 2009;325:957-8.
- [7] Yin ZY, Chong ZR, Tan HK, Linga P. J Nat Gas Sci Eng. 2016;35:1362-87.
- [8] Sloan ED. Nature. 2003;426:353-9.
- [9] Haligva C, Linga P, Ripmeester JA, Englezos P. Energy Fuel. 2010;24:2947-55.
- [10] Konno Y, Masuda Y, Hariguchi Y, Kurihara M, Ouchi H. Energy Fuel. 2010;24:1736-44.
- [11] Yang MJ, Fu Z, Jiang LL, Song YC. Appl Energ. 2017;187:180-8.
- [12] Chong ZR, Yin ZY, Linga P. 8th International Conference on Applied Energy (Icae2016). 2017;105:4963-9.
- [13] Wang Y, Li XS, Li G, Huang NS, Feng JC. Fuel. 2014;117:688-96.
- [14] Fitzgerald GC, Castaldi MJ, Zhou Y. Journal of Petroleum Science and Engineering. 2012;94-95:19-27.
- [15] Feng JC, Wang Y, Li XS. Appl Energ. 2016;174:181-91.
- [16] Schicks JM, Spangenberg E, Giese R, Steinhauer B, Klump J, Luzi M. Energies. 2011;4:151-72.
- [17] Feng JC, Wang Y, Li XS, Li G, Chen ZY. Energy. 2015;79:315-24.
- [18] Zhang LX, Yang L, Wang JQ, Zhao JF, Dong HS, Yang MJ, et al. Chemical Engineering Journal. 2017;308:40-9.
- [19] Wang Y, Feng JC, Li XS, Zhang Y. Appl Energ. 2016;181:299-309.
- [20] Wang Y, Feng JC, Li XS, Zhang Y, Li G. Energy. 2015;90:1931-48.
- [21] Yamamoto K DS. Fire in the ice. 2008;7.
- [22] Kvamme B. J Chem Eng Data. 2016;61:1280-95.