Enhancing the gas production from depressurized methane hydrate deposits via warm brine injection

Bin Wang[1,2], Hongsheng Dong[1], Jiafei Zhao[1*], Yongchen Song[1]

[1] Key Laboratory of Ocean Energy Utilization and Energy Conservation of Ministry of Education, Dalian University of Technology, Dalian 116024, China
[2] Energy Geoscience Division, Lawrence Berkeley National Laboratory, Berkeley CA 94720, United Status
* jfzhao@dlut.edu.cn

Introduction

With the rapid development of social economy, the consumption of environmental resource has been aggravated, and the environmental issues are getting more and more serious. Seeking alternative clean energy is an urgent task for solving the energy crisis (Obama, 2017). As the high energy density, massive storage, and wide distribution, natural gas hydrate has been considered as a potential non-conventional strategic energy resource, and aroused the worldwide attention (Lee et al., 2011). It is estimated that natural gas hydrates contain approximately 2/3 of the world's organic carbon content (Fan et al., 2017). The discovery of gas hydrate provides a new way of thinking for finding new and effective energy resources to replace increasingly exhausted traditional energy resources. Generally, the natural gas hydrate buried in the permafrost and beneath the sea floor with high pressure and low temperature conditions (Zhao et al., 2017) . Because of the severe existing environment of gas hydrate, gas extraction from the hydrate reservoir has been proven extremely challenging and yet to be realized. Thus, understanding of the gas production behavior from hydrate deposits is critical for the utilization of gas hydrate resources. Up to now, several methods, including depressurization, thermal stimulation, inhibitor injection, and gas exchange, have been proposed to produce natural gas from hydrate deposits (Temizel et al., 2016; Wang et al., 2017a). Among the methods mentioned above, consindering the feasibility of exploitation and the economic issues, the depressurization method has been considered as the most effective method (Li et al., 2016). However, the problem of hydrate reformation and ice generation can occur as the endothermic hydrate decomposition reaction, further resulting the blockage of gas/water flow path and gas production well (Wang et al., 2017b). Thus, providing sufficient heat is necessary for the efficient gas production from gas hydrate reservoir.

The treatment and utilization of concentrated brine is an urgent problem to be solved in the seawater desalination industry. At present, the typical operation is pouring it back into the sea without any treatment, which can seriously impact the marine environment. The stability of gas hydrate need specific pressure-temperature condition, and the emergence of ions in solution can shift the phase equilibrium curve of gas hydrate into more rigorous condition (Chong et al., 2015). Such as, the increase of salinity caused the enhancement in the equilibrium pressure when the temperature is kept at the same; or caused the decrease of the equilibrium when the pressure is constant. Injecting the warm brine (to simulate the concentrated seawater herein) into the hydrate reservoir has been considered as an effective means for enhancing the hydrate dissociation by (a) raising the reservoir temperature above the local hydrate phase equilibrium curve and (b) moving the hydrate phase phase equilibrium boundary into a more severe condition.

Method

In this study, the hydrate was formed *in-situ* using the excess gas method through controlling the temperature and pressure condictions in porous medium. The initial condictions including water saturation, temperature, and pore pressure are the same throughout all the experiments. After the hydrate sample prepared, the depressurization method was used to induce the hydrate dissociation, and simultaneously warm brine was injected into the hydrate reservoir to enhance the gas production efficiency. The gas production behavior including the profile of temperature, pressure, gas production rate, and water production rate was systematically analyzed. The enhancing effect of warm brine injection was evaluated through comparing the gas production efficiency with/without warm brine stimulation.

Results and discussion

Under the single depressurization method induced hydrate dissociation operation, the problem of hydrate reformation or/and ice generation may occur due to the insufficient heat supply. Both the reformed hydrate and generated ice can occupy the pores and throats in porous media, which can block the path of fluid flow and limit the gas-water flow in the reservoir and in the production well, further decreasing the gas production efficiency. In addition, the formed ice can also act as a "self-preservation" phenomenon wrapping around the hydrate particle, which limiting the mass transfer and preventing further hydrate decomposition. Wang et al. (2017b) directly observed the ice generation phenomena under rapidly depressurization induced hydrate dissociation using magnetic resonance imaging. And their results shown that the problem of ice generation can be effectively eliminated by controlling the gas production pressure. In addition, the problem of hydrate reformation also been experimental and numerical confirmed in lots of the past reports.

In this study, we proposed a method to eliminate the negative phenomenon of hydrate reformation and to enhance the gas production efficiency via injecting warm brine into the hydrate reservoir. On the one hand, the injected warm brine can supply heat for the endothermic hydrate dissociation reaction and promote the hydrate dissociation; on the other hand, the emergence of brine can shift the hydrate equilibrium curve into a more severe condition. The results shown that the phenomena of hydrate reformation and ice generation did not occur anymore in our experiments with warm brine injection. During the hydrate dissociation process, the reservoir temperature increased as the warm brine injection, however, the pressure in the reservoir was maintained at constant as the gas production pressure was kept at the same. The gas production rate was effectively enhanced, and the brine temperature and saline concentration have a positive effect on the promotion, but the energy dissipation will also increase. In addition, due to the low permeability in the hydrate reservoir, the inject warm brine is difficult to fill the whole pore space. Once the flow channel formed, the liquid will flow along the channel and will be difficult to permeate into the non-channel area. It's worth noting that the water content in the sediments can affect the stability of the depleted hydrate reservoir; therefore, the water content variation is also analyzed through evaluating the water production and injection. The results shown that the water production rate almost equals to the warm brine injection rate during the process of gas production, which means that the increasing water content in the sediments is equivalent to nearly the hydrate decomposed water.

Our experimental results confirmed that warm brine injection can be an effective mean for promoting the gas production from depressurized hydrate deposits, however, how to effectively use the injected energy is still a rigorous task in the future work.

References

Chong ZR, Chan AHM, Babu P, Yang M, Linga P (2015) Effect of NaCl on methane hydrate formation and dissociation in porous media. Journal of natural gas science and engineering 27, 178-189. doi: 10.1016/j.jngse.2015.08.055

Fan Z, Sun C, Kuang Y, Wang B, Zhao J, Song Y (2017) MRI Analysis for Methane Hydrate Dissociation by Depressurization and the Concomitant Ice Generation. Energy Procedia 105, 4763-4768. doi: 10.1016/j.egypro.2017.03.1038

Lee JY, Ryu BJ, Yun TS, Lee J, Cho GC (2011) Review on the gas hydrate development and production as a new energy resource. KSCE Journal of Civil Engineering 15, 689-696. doi: 10.1007/s12205-011-0009-3

Li X, Xu C, Zhang Y, Ruan X, Li G, Wang Y (2016) Investigation into gas production from natural gas hydrate: A review. Applied Energy 172, 286-322. doi: 10.1016/j.apenergy.2016.03.101

Obama B (2017) The irreversible momentum of clean energy. Science 355, 126-129. doi: 10.1126/science.aam6284

Temizel C, Betancourt D, Tiwari A, Zhang M, Aktas S, Quiros F (2016) Optimization of Enhanced Coalbed Methane Recovery With C02 Injection, SPE Argentina Exploration and Production of Unconventional Resources Symposium. Society of Petroleum Engineers. doi: 10.2118/180973-MS

Wang B, Dong H, Liu Y, Lv X, Liu Y, Zhao J, Song Y (2017a) Evaluation of thermal stimulation on gas production from depressurized methane hydrate deposits. Applied Energy. doi: 10.1016/j.apenergy.2017.08.005

Wang B, Fan Z, Wang P, Liu Y, Zhao J, Song Y (2017b) Analysis of depressurization mode on gas recovery from methane hydrate deposits and the concomitant ice generation. Applied Energy. doi: 10.1016/j.apenergy.2017.09.109

Zhao J, Wang B, Sum AK (2017) Dynamics of hydrate formation and deposition under pseudo multiphase flow. AIChE journal 63, 4136-4146. doi: 10.1002/aic.15722