Journal of Natural Gas Science and Engineering 55 (2018) 154–164

Contents lists available at ScienceDirect

Journal of Natural Gas Science and Engineering

journal homepage: www.elsevier.com/locate/jngse

Effects of vertical center well and side well on hydrate exploitation by depressurization and combination method with wellbore heating

Yunpei Liang[a], Shu Liu[a], Wenting Zhao[b], Bo Li[a,*], Qingcui Wan[a], Gang Li[c]

[a] State Key Laboratory of Coal Mine Disaster Dynamics and Control, Chongqing University, Chongqing, 400044, China
[b] School of Civil Engineering & Architecture, Linyi University, Linyi, Shandong, 276000, China
[c] Key Laboratory of Gas Hydrate, Guangzhou Institute of Energy Conversion, Chinese Academy of Sciences, Guangzhou 510640, China

ARTICLE INFO

Keywords:
Natural gas hydrate
Vertical center well
Vertical double-side wells
Depressurization
Wellbore heating

ABSTRACT

The effects of depressurization and the combination method with wellbore heating on vertical center well and vertical side well on hydrate exploitation were investigated and compared in this study. Six combinations of experimental groups were conducted using different exploitation methods (i.e., depressurization and the combination method) and different types of wells (i.e., vertical center well and vertical double-side wells). The results show that the lower the production pressure is, the better it can generate hydrate productions. Meanwhile, it is further confirmed that the heating process can greatly increase the gas production rate of hydrates. In addition, when using depressurization within a certain exploitation range, the location of the production well has little impact on the effects of hydrate exploitation. However, with double-side wells using the combination method, the effect of driving force in hydrate decomposition is weakened due to the larger heat loss. Therefore, when the heating well is located close to the boundary of the hydrate deposit, the use of double-side wells is less productive than that of a center well. As a result, when using the depressurization method, the location of the production well within the exploitation zone should be as close to the coastal line as possible with a stable hydrate deposit layer. On the other hand, when wellbore heating is applied, it is suggested that the heating well should be arranged near the center of the hydrate deposit. Furthermore, it is found that there is a right-skewed bell curve shape relationship between the exploitation time and the energy generation level using the combination method.

1. Introduction

As the environmental issues caused by the exploitations and the consumptions of traditional energy sources continue to worsen, Natural gas hydrate (NGH) is found to be one of the most efficient source of clean high-reserves energy that can drastically reduce these problems. Currently, the traditional sources with the highest percentage of use are fossil fuels which include coal, natural gas, and oil, occupying more than 70% of the total energy consumption worldwide (Chong et al., 2016; Song et al., 2014). However, fossil fuels are non-renewable and release post-consumption pollutants such as sulfide, dust and CO_2 gas that are severely detrimental to our environment, negatively affecting the human health while contributing to the greenhouse effects (Kvenvolden, 1999). Therefore, humans need to find alternative ways for energy exploitation that are both economical and sustainable, fulfilling the needs of our daily energy consumption as well as protecting our environment.

Since the first discovery of NGH in the stratum in mid 1960s, experts and scholars from all over the world have been studying its composition, carbon reserves and efficacy to understand how to best utilize this new source of energy (Babu et al., 2015). Early researchers found that NGH is an ice-like solid comprised of water and methane, formed under a high-pressure and low-temperature environment, and its interior is a crystalline cage compound (Chong et al., 2016; E.D.S and Koh, 2007; Sloan, 1998a). To date, there have been three types of NGH discovered that are distinguished by their structures, namely structure I, structure II and structure H (Kurnosov et al., 2001; Loveday et al., 2001; Tariq et al., 2014). As the research progressed, more emphasis was put on studying carbon reserves of NGH. It was found that the global organic-carbon gas content of methane gas released by global NGH is twice as much as the organic carbon already found in fossil fuels, and that one unit volume of pure NGH releases about 160 unit volumes of methane gas under the standard conditions (Moridis et al., 2009). Moreover, NGH decomposes to produce only methane gas and water (E.D.S and Koh, 2007; Sloan, 1998b), making it a clean and alternative source of energy to meet the growing demand on energy consumption (Yin et al.,

* Corresponding author.
E-mail address: libo86@cqu.edu.cn (B. Li).

https://doi.org/10.1016/j.jngse.2018.04.030
Received 24 February 2018; Received in revised form 26 March 2018; Accepted 19 April 2018
Available online 26 April 2018

2016). Therefore, recent researchers have moved their attention to studying the way to exploit NGH. Currently, the feasible methods for hydrates exploitation include depressurization, heat stimulation, inhibitor method, combination method and CO_2 - CH_4 replacement method (Babu et al., 2013, 2015; Collett et al., 2014; Sloan, 2007; Haligva et al., 2010; Yousif and Sloan, 1991; Pang et al., 2009; Fan et al., 2006; Morohashi et al., 2005; Rice, 2003; Dashti et al., 2015; Aman et al., 2016; Aminnaji et al., 2017).

To investigate the efficiency of NGH extraction methods, many studies have been carried out and some important results have been obtained. Li et al. (2012a) compared the dissociation behavior of hydrates in a pilot-scale hydrate simulator (PHS) with that in a cubic hydrate simulator (CHS) by depressurization. They found that the scale of hydrate sediment showed a negative influence on the gas production and water production during the hydrate decomposition, but it had little effect on the temperature change in the hydrate reservoir. Jiang et al. (2012) analyzed the gas production properties with the use of a 3D numerical model in depressurization, and the results showed that a higher initial temperature and larger absolute permeability could promote hydrate dissociation and gas production. However, the increase of the initial reservoir pressure had a negative effect on hydrate dissociation. In addition, it was confirmed by many other studies (Li et al., 2014a; Ji et al., 2001; Konno et al., 2010) that although being more accessible and economical in energy gain in contrast to the thermal stimulation method, depressurization does not ensure high production efficiency due to its long exploitation time. Subsequently, thermal stimulation with heated water injection was investigated by other researchers. Specifically, Yang et al. (2010) conducted an experiment on hydrate decomposition in a three dimensional mid-sized reactor using a cyclic hot-water injection process. The result indicated that the increase of hydrate saturation in the sediment and hydrate temperature had positive effects on the rise of energy efficiency but the increase of hot water temperature and well pressure led to the decrease of it. Furthermore, Li et al. (2011) simulated the gas production of the hydrate sediment at the Shenhu marine area using the huff-and-puff method in a horizontal center well, and it was confirmed by numerical study that the production rate could be improved by raising the temperature of the injected water in a limited range. Some other related researches (Li et al., 2012b; Kawamura et al., 2007) also drew the identical conclusion that the heated water injection had promoting capacity for hydrate decomposition and gas production. However, the hot water injection may actually have a limited effect on the increase of field-scale hydrate exploitation rate as the energy loss caused by long transportation distance of heated water has never been considered in the above studies. In order to obtain high production rate and reduce energy loss, the wellbore heating, an in-situ heating method that is merely studied can be considered in hydrate exploitation.

It is widely believed that the type and arrangement of wells are also influencing factors for the gas production in the hydrate reservoir. Feng et al. (2015a) synthesized methane hydrates and conducted decomposition experiment in a pilot-scale hydrate simulator using the combination method with both a horizontal well and a vertical well. Through the comparison of various parameters (e.g. gas production, temperature, production time, etc.), it was found that the exploitation efficacy using a horizontal well was better than that of a vertical well. Subsequently, Feng et al. (2015b) utilized a three-dimensional experimental apparatus to produce the hydrate in a cubic reactor with double-horizontal wells using depressurization combined with warm water injection. Moreover, the comparison and analysis were carried out by numerical simulation. The results of the two methods were in good agreement with each other, and the exploitation method of depressurization combined with warm water injection in double-horizontal wells was promising. Wang et al. (2014) compared hydrate dissociation behaviors by a new method named Five-spot thermal huff and puff (HP-5S) with that in a vertical center well by huff and puff, the result of which indicated that the production performance of this five-spot vertical well design was much better than that of the later. Afterwards, Li et al. (Liang et al., 2015) adopted a five-spot well (5S) system with horizontal wells to numerically simulate the hydrate production properties with the use of depressurization combined with thermal stimulation. After the comparison with another two kinds of two-spot well (2S) systems, they found that a greater production rate could be obtained in the 5S system under reasonable heat injection and production pressure than that in the two-spot well (2S) systems. From the previous studies, we can see that the production efficiency is affected by the well designs. However, much of the research is about horizontal well placement and only a few studies are about vertical well arrangement.

The location of the production well not only affects the hydrate decomposition characteristics, it also influences the stability of the hydrate sedimentary layer, which is one of the key factors to ensure the safety and efficiency of NGH production. Therefore, in this paper, we utilized a laboratory independent apparatus, which is equipped with a three-dimensional reactor with three vertical wells. With the use of this device, the production properties of hydrates were studied by using depressurization and the combination method with wellbore heating in single center well, single side well and double-side wells, respectively. At the same time, it is verified that the added heat can greatly promote gas production. This paper mainly analyzed the cumulative gas production during hydrate decomposition, the temperature change in the reactor and the energy consumption and net energy gain.

2. Experimental apparatus

In this paper, the experimental system shown in Fig. 1 is designed to study the synthesis and decomposition of hydrates in porous media. The structure of the system is shown in Fig. 2. The main device is a vertical cylindrical stainless steel reactor with a cubic cavity. The length, width and height of the cubic cavity are 100 mm, 100 mm and 150 mm respectively with the capacity of 1.5 L. It can withstand the pressure of 0 Mpa–25 Mpa, which can simulate hydrate occurrence in marine and permafrost environments. The pressure in the reactor is measured by an inlet pressure sensor provided at the bottom of the reactor and an outlet pressure sensor provided at the outside of the reactor. The reactor is equipped with nine temperature sensors, named T1 - T9, respectively. As shown in Fig. 2, the nine temperature sensors are distributed in the horizontal center plane of the reactor. The length of the square plane is 80 mm, on the corner of which the temperature sensors T1, T3, T7 and T9 are located, respectively, and T5 is on the center. The distance between each sensor on the four corners and the reactor boundary is 10 mm and the distance between two adjacent sensors is 40 mm. During the experiment, the nine temperature sensors are used to monitor the temperature change in the reactor. The reactor is connected to the outside through three wells perpendicular to the center plane of the reactor, which are named as No.1 well, No.2 well and No.3 well, respectively. It can be seen from Fig. 2 that No.2 well is set in the middle of the center plane as center well, and the other two are side wells. The vertical well is 10 mm in diameter, and the length of it is equal to 4/5 of height of the reactor. Hence, the lower end of the vertical well is 30 mm to the bottom of the reactor. The vertical axes of the three vertical wells are evenly arranged with a resistance of 73.5 Ω, and the hydrate can be exploited by wellbore heating method. The produced gas and water are revealed through four grooves on the surface of the vertical well.

The temperature control system uses wellbore heating and cooling system. In this system, the outside of the reactor is surrounded by the water in the thermostatic zone and the temperature of the device is adjusted so that the temperature range available in the water zone is from −5 °C to 30 °C for the synthesis and decomposition of the hydrate, with an error range of ± 0.1 °C . At certain pressure and temperature, it can be used to simulate the synthesis and exploitation of hydrates in the marine environment and permafrost.

The experimental gas supply system includes a methane gas cylinder, a gas booster pump and a high pressure gas storage tank. The