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GAS PRODUCTION FROM HYDRATE RESERVOIR IN SHENHU AREA OF SOUTH CHINA SEA BY DEPRESSURIZATION AND MULTI-VERTICAL WELL PATTERNS

Tao Lv[1,2,4], Xiaosen Li[1,2,3], Zhaoyang Chen[1,2,3,*], Yu Zhang[1,2,3], Kefeng Yan[1,2,3], Jing Cai[1,2,4]

1 Guangzhou Institute of Energy Conversion, Chinese Academy of Sciences, Guangzhou 510640, China

2 CAS Key Laboratory of Gas Hydrate, Guangzhou 510640, China

3 Guangdong Provincial Key Laboratory of New and Renewable Energy Research and Development, Guangzhou 510640, China

4 University of Chinese Academy of Sciences, Beijing 100049, China

ABSTRACT

A physical model of multi-layer hydrate reservoir contained free gas was established for gas hydrate reservoir at W17 site in Shenhu area of South China Sea, and the effects of multi-vertical well patterns and inter-well distance on the production characteristics of hydrate reservoir by depressurization were investigated by numerical simulation. The results indicated that the production is affected by inter-well interference. The cumulative amount of dissociated gas and gas production for each well in multi-vertical well patterns are always less than that in single well alone after 36 days. For the hydrate produced by multi-vertical well patterns, the cumulative amount of water for each well can be effectively reduced compared to that by single well alone. From the percentage of hydrate dissociation and gas liquid ratio R_{GW} perspectives, the 40 m well distance is more conducive to the exploitation of the hydrate reservoir.

Keywords: hydrate, multi-vertical well patterns, South China Sea, depressurization, inter-well interference, well distance

1. INTRODUCTION

Natural gas hydrate is regarded as one of the alternative energy sources of traditional fossil fuels in the future, due to its large reserves, wide distribution and excellent environmental performance. In recent years, there have successively carried out several production tests of gas hydrate reservoir, and 5 of which were conducted in marine sediments [1]. The first deep sea production test of hydrate reservoir was conducted at the eastern of Nankai Trough, Japan in 2013, and the cumulative amount of gas production is about 119500 Nm^3 during 6 days [2]. A continuous production test was implemented in Shenhu area of South China Sea (SCS). The production test lasted for 60 days, and 309000 Nm^3 gas was produced[3].

The numerical simulation is a convenient method to evaluate and predict the production characteristics of actual hydrate reservoir. Many simulation studies on hydrate reservoir in Shenhu area of SCS have been carried out. Li et al [4] established a representative model of SH7 site in SCS, and investigated the production characteristic of hydrate reservoir by means of depressurization and thermal stimulation. Su et al [5] investigated the gas production of SH2 site in SCS by the huff-and-puff method, and the results indicated that this method is not conductive to commercial production. Feng et al [6] evaluated the production performance of hydrate reservoir at GMGS2 site in SCS by depressurization with horizontal well, and the results showed the hydrate dissociation rate is low. Based on the production data of 2017 test in Shenhu area of SCS, Chen et al [7] predicted a mid- to long-term (2~3 years) gas production for SH2 and SH7 site.

In most studies, the models for hydrate reservoir in Shenhu area of SCS are almost the single hydrate layer, and the pore space is filled with hydrate and water two phases, not involved in free gas. However, the hydrate layer at W17 site in Shenhu area of SCS contains a small amount of free gas (7.8%), and the bottom layer is consisted of water and hydrocarbon gas [8]. There is no relevant report about this aspect. In addition, like the exploitation of traditional oil and gas, the multi-wells combined production mode is essential for future commercial production of hydrate reservoir. In this work, a physical model of multi-layer hydrate reservoir contained a small amount of free gas for Shenhu area of SCS was established, and the reservoir conditions are based on the production test in 2017 at W17 site. The TOUGH+HYDRATE was used to simulate the production behavior of hydrate reservoir induced by depressurization using by multi-vertical wells mode. The influence of inter-well interference on the production characteristics of hydrate reservoirs was analyzed and a suitable inter-well distance was optimized and determined.

2. GEOLOGICAL BACKGROUND AND PRODUCTION TEST

Since from 2007, the China Geological Survey (CGS) carried out several drillings and samplings in Shenhu area of SCS, and estimated that there riches of gas hydrate resources. The average heat flux of seabed is about 76 mW/m^2. The analysis results of hydrate samples revealed that the salinity of pore water is between 2.90 wt% and 3.15 wt%. Unlike hydrate reservoirs in other regions, the hydrate bearing sediments in Shenhu area of SCS is dense argillaceous silt type, and the clay content is not less than 20% [9]. As a result, the effective permeability of hydrate reservoir is very low, which poses a great challenge to the exploitation of hydrate reservoirs in this area.

In 2017, the gas production test from hydrate was first conducted at W17 in Shenhu area of SCS by depressurization method. A cumulative amounts of 309000 Nm^3 gas was produced in 60 days. It can be indicated from this test that the hydrate in argillaceous silt of marine sediments could be continuously and safely production.

3. NUMERICAL MODELS AND SIMULATION METHODS

According to the logging and exploration data from W17 site, the hydrate reservoir belongs to pore-filled hydrates, and the water depth of this area is about 1266 m. The hydrate layer I and II is located at 201~236 m, 236~251 m below seabed, respectively, and the lower mud layer is located at 251~278 m below seabed. There are a little free gas (about 7.8%) contained in hydrate II and mud layer. The effective porosity is about 0.35, and the hydrate saturation is about 0.34. The effective permeability is between 1.5 mD and 7.4 mD [8]. In this work, the parameters of numerical model are basically consistent with the actual situation. The other values of relevant parameters are as follows: the seabed temperature is 3.7 °C, and the geothermal gradient is 0.0443 °C/m. The salinity of pore water is 3.05 wt%. The true density of sediment is 2.2 kg/m^3.

3.1 Numerical models and domain discretization

Based on the geometric symmetry in multi-vertical well patterns, a three dimensional physical model between two vertical wells was established in this work, to investigate the influence of inter-well interference on gas production from hydrate induced by depressurization, which is shown in Fig 1. The over and under burden is 20 m, respectively, and which are permeable. Some assumptions have been made: (1) All wells are symmetrical and uniform distribution in vertical well pattern. (2) The production of each vertical well is consistent. (3) The cylindrical production wells can be approximately replaced by equilateral cube.

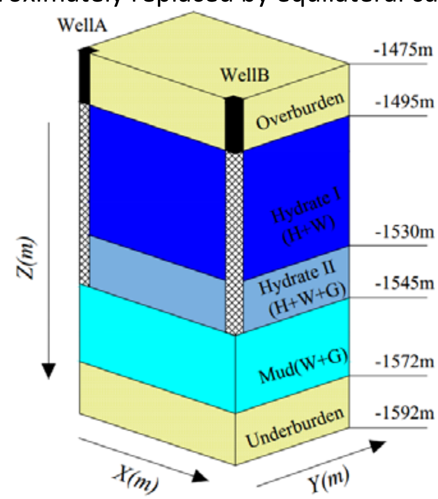

Fig 1. The schematic diagram of physical model at W17 site between two vertical wells in multi-vertical well patterns

For different inter-well distance of 30 m, 40 m, 50 m and 60 m, the cubic domain region is discretized into 22×19×89, 27×24×89, 32×21×70, and 32×20×70 grid blocks in (X, Y, Z) direction, respectively. A fine discretization was made in the vicinity of the production wells. The upper and lower boundaries of the simulated area and the production wells are defined as inactive grids.

3.2 Production method and well design

In this work, constant-depressurization method is used to produce gas from hydrate, and the wellbore pressure is 4.5 MPa. The cross section of production wells is 0.2 m square, and the production interval is through hydrate layer I and II. The value of permeability in the production wells is assumed as 1000 D, and the porosity is 1. Fluid flow in the production wells is assumed following Darcy's law and there is no capillary force in the production wells.

3.3 Simulation methods

In this work, the numerical simulation is based on TOUGH+HYDRATE code, which has been widely used to guide the production of actual gas hydrate reservoirs. In simulation process, the primary variable switch method (PVSM) is used to solve the main parameters of the model equation, and the secondary parameters are obtained by other constitutive equations. The fluid flow in porous media is calculated by Darcy's law.

4. RESULTS AND DISCUSSION

The gas and water production of each well from hydrate reservoir by multi-vertical well patterns (inter-well distance is 40 m) and single well alone during 5 years are compared in Fig 2 and Fig 3, respectively.

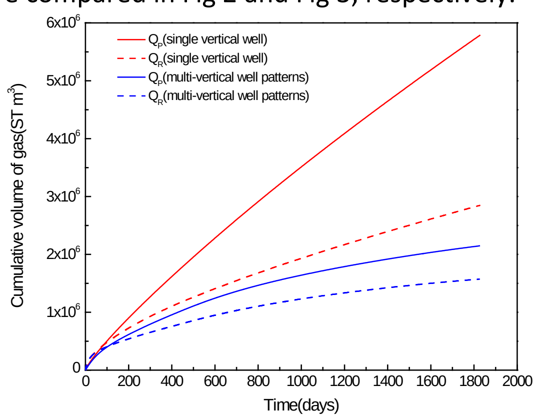

Fig 2. Comparison of the cumulative amount of Q_R and Q_P for each well by single and multi-vertical well patterns

After 36 days production, the cumulative amount of hydrate dissociated gas Q_R and wellhead gas production Q_P for each well in multi-vertical well patterns becomes less than that in single well alone, especially for Q_P. It is mainly because the fluid flow between wells regions could be hindered by inter-well interference in multi-vertical well patterns, and a considerable part of the Q_P is from dissolved gas in pore water and free gas in reservoir. For the two cases, the Q_R is slightly higher than that of Q_P within the first 100 days, and then falls below the latter. As production proceeds, the deviation between Q_R and Q_P increases. But the deviation for multi-vertical well patterns is significantly less than that for single well alone. Within 5 years production, the deviation for single well alone is up to 2.94×10^6 Nm^3, which is almost 5 times higher than that for multi-vertical well patterns, about 5.75×10^5 Nm^3, which also indicates that more dissolved gas or free gas are produced from hydrate reservoir for single well alone.

From Fig 3, for both production well modes, the instantaneous water production rate Q_W and the cumulative amount of water production M_W have similar variation trend over production time. But the Q_W and M_W for each well in multi-vertical well patterns are always less than that for single well alone, and the deviation is increasing with time. Up to 5 years production, M_W of the former is 4.96×10^8 kg, which is about 5/9 of the latter. This indicates that the water production can be effectively reduced by multi-vertical well patterns.

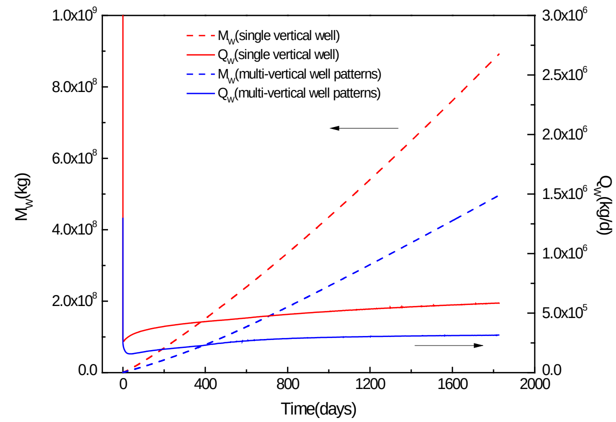

Fig 3. Comparison of water production of Q_W and M_W for each well by single and multi-vertical well patterns

Fig. 4 and Fig. 5 shows the percentage of hydrate dissociated, and variations of gas liquid ratio R_{GW} within 5 years production for different inter-well distances, respectively. As the well spacing increased from 30 m to 60 m, the percentage of hydrate dissociated decreases. After 5 years production, the hydrates dissociate completely 100% for the well spacing of 30 m, while only 59% of hydrates dissociate in case of 60 m well spacing. From Fig. 5, with the increase of inter-well distance, the R_{GW} decreases in the early and middle stages (about 700 days), then slightly increases with time.

From the percentage of hydrate dissociated and gas liquid ratio perspectives, the 40 m inter-well distance could be help to the hydrate reservoir production. About 92% of hydrate dissociated in 5 years for 40 m case, and the gas liquid ratio maintain at relative higher values.

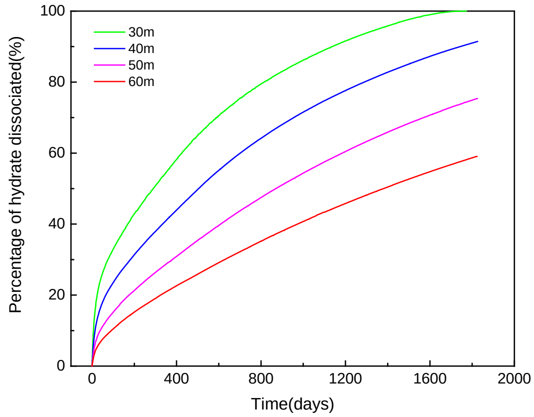

Fig 4. Percentage of hydrate dissociated with time for different inter-well distance

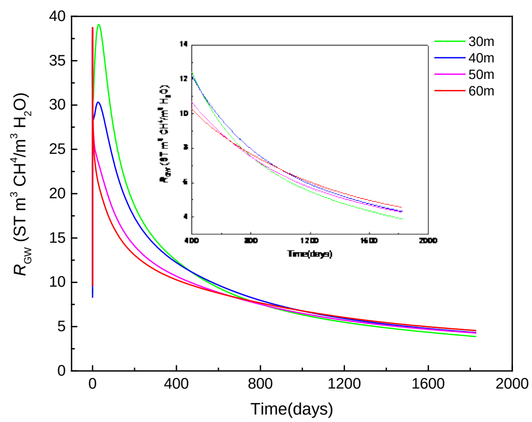

Fig 5. Variations of gas liquid ratio R_{GW} with time for different inter-well distance

5. CONCLUSIONS

A physical model of multi-layer hydrate reservoir contained free gas was established for gas hydrate reservoir at W17 site in Shenhu area of SCS, and the effects of inter-well distance on the production characteristics of hydrate reservoir was investigated. The following conclusions were obtained: (1) The cumulative amount of dissociated gas and gas production from each well by multi-vertical well patterns are always less than that by single well alone after 36 days production, and there is more dissolved gas and free gas produced from hydrate reservoir for t single well alone. (2) The instantaneous and cumulative amount of water production from each well can be effectively reduced by multi-vertical well patterns. The cumulative water production is about 5/9 of that for single well alone in 5 years because the fluids flow between wells regions are hindered by the inter-well interference. (3) The percentage of hydrate dissociated decreases with the increase of well spacing. Combining the hydrate dissociation ratio and gas liquid ratio R_{GW}, the 40 m of well spacing is more conducive to the exploitation of the hydrate reservoir.

ACKNOWLEDGEMENT

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