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Research paper

Production potential and stability of hydrate-bearing sediments at the site GMGS3-W19 in the South China Sea: A preliminary feasibility study

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ABSTRACT

According to the preliminary geological data of gas hydrate bearing-sediments (GHBS) at site GMGS3-W19 in the third Chinese expedition to drill gas hydrates in 2015, a production model using three different recovery pressures was established to assess the production feasibility from both production potential and geomechanical response. The simulation results show that for this special Class 1 deposit, it is a little hard for gas production rate to reach the commercial extraction rate because the degree of hydrate dissociation is limited due to the low reservoir permeability and the permeable burdens. However, the free gas accumulating in the lower part of the GHBS can significantly increase gas-to-water ratio. It also generates many secondary hydrates in the GHBS at the same time. Decreasing the well pressure can be beneficial to gas recovery, but the recovery increase is not obvious. In term of geomechanical response of the reservoir during the gas recovery, the permeable burdens are conducive to reduction of the sediment deformation, though they don't facilitate the gas recovery rate. In addition, significant stress concentration is observed in the upper and lower edges of GHBS around the borehole during depressurization because of high pressure gradient, and the greater the well pressure drop, the more obvious the phenomenon. Yield failures and sand production easily take place in the edges. Therefore, in order to achieve the purpose of safe, efficient and long-term gas production, a balance between the production pressure and reservoir stability should be reached at the hydrate site. The production pressure difference and sand production must be carefully controlled and the high stress concentration zones need strengthening or sand control treatment during gas production. Besides, the sensitivity analyses show that the hydrate saturation heterogeneity can affect the production potential and geomechanical response to some extent, especially the water extraction rate and the effective stress distribution and evolution. Increasing GHBS and its underlying free gas formation permeabilities can enhance the gas production potential, but it probably introduces geomechanical risks to gas recovery operations.

1. Introduction

Natural gas hydrates distribute widely in the offshore marine sediments and onshore permafrost area under specific low-temperature and high-pressure conditions (Kvenvolden, 1993). Over the last few decades, much attention has been directed

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toward them as energy resources and for their environmental impact (Demirbas, 2010; Moridis et al., 2011a). According to the estimation of Klauda and Sandler (2005), there are 74,000 Gt of methane trapped in gas hydrates within marine zones, three orders of magnitude larger than current worldwide conventional natural gas reserves. Therefore, the oceanic sediment-hosted gas hydrates are supposed to be the future hydrocarbon source of energy.

Up to now, many countries, such as the United States, Canada and Japan, have performed extensive investigations aiming at commercial production from hydrate deposits (Collett et al., 2009; Konno et al., 2016). Although gas hydrate investigation started relatively late in China, a series of drilling programs and field surveys have been carried out sequentially (Fu et al., 2013; Lu et al., 2011; Wu et al., 2007; Yang et al., 2015; Zhang et al., 2014). Based on the field survey and coring, the occurrence of gas hydrates was confirmed in the South China Sea, and this region was regarded as a potential target area. In order to evaluate the production feasibility, especially the production potential, numerical simulations were widely performed. According to the characteristics of GHBS in the Shenhu area of the South China Sea, Zhang et al. (2010) established a typical model of hydrate deposits to evaluate the production potential and efficiency by means of depressurization and thermal stimulation using the horizontal well. Then using the data from drilling and logging at sites SH2, SH3 and SH7 in the first Chinese expedition to drill gas hydrates, Li et al. (2010a,b, 2011) investigated gas production from these sites by depressurization and the combination of depressurization and thermal stimulation, respectively, employing both vertical and horizontal wells. Meanwhile, the single vertical well production design was also considered by Su et al. (2010, 2011, 2012, 2013) in their simulations to assess the gas production potential by depressurization and alternately producing fluid as well as injecting hot water (huff-and-puff). They all concluded that gas production from these reservoirs using current techniques is not economically viable because of low intrinsic permeability of the GHBS and permeable overburden and underburden. After that, Li et al. (2013) and Sun et al. (2015) further confirmed the effects of burden permeabilities on production behaviour in the Shenhu area. They indicated that the hydrate deposit with impermeable burdens was expected to be the potential gas production target. In addition, some numerical simulations on gas production using warm brine stimulation combined with depressurization based on the Shenhu hydrates were launched by Feng et al. (2013, 2014), which showed that a higher injection rate could enhance the hydrate dissociation and gas production rates, but give less favourable gas-to-water and energy ratios. Based on the above studies, Jin et al. (2015, 2016) also performed some numerical simulations, especially production optimization, aiming to confirm the production feasibility again. Recently, the gas production behaviour at the GMGS2-Site 16 in the Pearl River Mouth Basin was evaluated by Feng et al. (2015) using some available data. They found that the average gas production rate could obtain the same order of magnitude with the minimum production level for the commercial viability. In 2016, Huang et al. (2016) systematically investigated the relative importance of six main geologic factors on gas production from GHBS. The results suggested that hydrate reservoirs with high permeability, moderate porosity, moderate-to-high hydrate saturation and the low initial pressure favour gas recovery. The above research has properly evaluated the production potential of typical GHBS in the South China Sea; however, the geomechanical analysis for gas production in this area has never been conducted and reported. This important factor determines whether the deposit could be safe for long-term production. Therefore, the production performance and geomechanical behaviour should be addressed together in order to determine the production candidate area and optimal production process. Here, we used available data from *in situ* measurement of site GMGS3-W19, a field test candidate reservoir, in the third Chinese expedition to drill gas hydrates in 2015 to construct a two-dimensional production model, and then used different pressure drops in the well to analyze the production feasibility from both production potential and geomechanical response. The optimal balance between gas production and reservoir stability is expected to be reached and the greatest risk area of sand production during depressurization can be revealed. In addition, the sensitivity analyses including hydrate saturation heterogeneity, hydrate formation permeability and the underlying free gas formation permeability are performed. Our simulation results can give some valuable suggestions for the coming field test for gas hydrates in the South China Sea.

2. Simulation model

2.1. The numerical simulation code

For the analysis of the coupled flow, thermal and geomechanical processes involved in this study, we coupled the TOUGH + HYDRATE simulator (Moridis et al., 2008) to the commercial geomechanical code FLAC3D (Itasca, 2011) to perform the numerical investigations of the coupling processes. The availability has been demonstrated by previous studies, and has been generally applied to perform the research on the geomechanical behaviours of both marine and permafrost GHBS (Moridis et al., 2013; Rutqvist et al., 2009, 2010, 2011, 2012; Rutqvist and Moridis, 2008, 2009). The TOUGH + HYDRATE software was developed from TOUGH V2.0 by the Lawrence Berkeley National Laboratory, and has been widely used for gas recovery from hydrate reservoirs (Li et al., 2010a,b; 2011; Moridis et al., 2004, 2009, 2011b; Ramesh et al., 2014; Sun et al., 2016; Vedachalam et al., 2015). Both equilibrium and kinetic models of hydrate formation and dissociation are included. These models cover four phases (gas, liquid, ice, and hydrate) and four mass components (water, methane gas, hydrate, and water-soluble inhibitors) with each component existing in each phase (Moridis et al., 2008). TOUGH + HYDRATE can investigate non-isothermal hydration reactions, phase behaviour, and fluid and heat flow under conditions generally found within natural CH_4-hydrate systems in complex geologic media (Zhang et al., 2009). Meanwhile, the FLAC3D code is generally employed in geotechnical engineering analysis. It has built-in constitutive models suitable for soils and rocks, including various common elastoplastic models for quasistatic yield and failure analysis and viscoplastic constitutive models for time-dependent analysis, which could be adopted directly or modified for investigating the geomechanical response of GHBS during gas production (Rutqvist et al., 2012). In this study, the Mohr-Coulomb yield criterion is considered.

In this coupled simulator, the two constituent simulators (i.e., TOUGH + HYDRATE and FLAC3D) were also linked through a coupled thermal-hydrological-mechanical (THM) model of GHBS, which has been illustrated in detail by Rutqvist (2008), Rutqvist et al. (2012), and Rutqvist and Moridis (2009). Because solving the fully coupled system should carry a large computational cost, one-way coupled analysis was employed at present in our simulation. That is, the effects of pressure, temperature and hydrate saturation changes on the geomechanical behaviours of GHBS were considered, but the effect of the mechanically induced changes in hydraulic and wettability properties on the multiphase flow character was not considered.

2.2. System description

The geological system simulated in this study is located in the Shenhu area (Fig. 1). In 2015, there were two gas hydrate