Thermal-hydraulic-mechanical simulation on wellbore stability during methane hydrate production by depressurization method

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ABSTRACT

Methane hydrate, a solid compound consisting of methane and water molecules, has great potential as a new energy source and has been studied for scientific and technical advances. Among the production methods for methane recovery, depressurization has been proven as the most effective and productive method through the previous production test and numerical studies. However, the significant mechanical responses of hydrate-bearing sediment such as large volume contraction, and subsidence are possibly generated during methane production induced by depressurization. Moreover, this phenomenon is further exacerbated by strength and stiffness reduction in the hydrate-bearing sediments (HBS) as hydrate dissociation advances. As a result, the highest compressive strength is concentrated in the vicinity of the production wellbore and the wellhead. Therefore, it is essential to be addressed and evaluated that the mechanical responses of HBS and the stability analysis of the production well during depressurization and hydrate dissociation in order to prevent destruction of the production facilities and consequent leakage of the methane gas. In this study, a reservoir-scale THM coupled simulation using FLAC3D was conducted to evaluate the mechanical responses of HBS and the stability of the wellbore during the methane production by depressurization at the Ulleung Basin. The structural design and the mechanical properties including the dimensions of wellbore components, and interface properties related to the interaction behavior between the sediment and the wellbore, were considered in the three-dimensional model.

Keywords: methane hydrate, stability, production wellbore, depressurization

1 INTRODUCTION

Methane hydrate has great potential as a new energy source and has been intensively studied in hopes of making new scientific and technical advances. More than twenty field projects are currently underway around the world (Beaudoin et al. 2014), but due to a lack of production techniques there have been no commercial projects in this area. Moreover, significant mechanical responses of hydrate-bearing sediment, such as large volume contraction and subsidence can be generated during methane production induced by depressurization. In addition, the strength and stiffness of the hydrate-bearing sediments (HBSs) are reduced by the dissociation of methane hydrate cementing (or pore filling) the sediment particles. The highest compressive strength is then concentrated in the vicinity of the production wellbore. Therefore, in order to prevent the destruction of production facilities and consequent leakage of methane gas, it is essential to address the abovementioned problems by evaluating the mechanical responses of hydrate-bearing sediment and analyzing the stability of the production well during depressurization and hydrate dissociation.

In this study, a thermal-hydraulic-mechanical coupled simulation was carried out to evaluate a stability of a pilot test planned at the Ulleung Basin. The all components of the vertical production well and interface properties related to interaction behavior were considered in the 3D model. The stress evolution and the instability of the production well were analyzed considering penetration, construction and depressurization sequences.

2 SITE OF INTEREST

2.1 Site description

The Ulleung Basin in the East Sea is one of the world's known methane hydrate deposits and it is located at the southwestern corner of the East Sea, South Korea. The potential for methane hydrate was identified and the accumulation of methane hydrate was estimated as about 0.6 billion tons (Lee et al. 2013).

The site UBGH2-6 is the northern UBGH2 sites and considered a most feasible site for a field pilot test (Ryu et al. 2013) based on the obtained data from drilling expeditions in 2007 and 2010. The core analysis and field-log data indicate that the sediments of the site UBGH2-6 contains the intercalated hydrate-bearing sandy layers with highly plastic silty soil (Kim et al.

2013).

2.2 Input properties

The input properties for thermal, hydraulic, and mechanical coupled analyses of the site UBGH2-6 were determined by Kim et al. (2017) based on core analysis and logging data from UBGH2.

The initial hydrate saturation in the sand layers was set to 65% and it was assumed that there is no hydrate in the mud layers. The coefficients of earth pressure at rest (K_0) of the mud and sand layers were calculated to be 0.625 and 0.577, respectively using Jaky's law (1948), in order to simulate the initial stress condition, and assuming that the sediment is classified as normal consolidated soil. More details about the methods and base data of the determination of THM properties of site UBGH2-6 are described in Kim et al. (2017).

2.3 Geometry and Initial Condition

UBGH2-6 has a water depth of 2,157 m, and seafloor temperature of 0.482 °C with a geothermal gradient of 112 °C/km (Figure 1). The hydrate occurrence zone ranges from 140 mbsf to 153 mbsf (meters below seafloor), consisting of four sand layers and three mud layers (Figure 2). A sediment deposit of 200 m deep and 100 m wide is modeled as a cylindrical model divided into 54 blocks in the radial direction and 65 blocks in the axial direction. The vertical production well is positioned at the center of the reservoir model, and the location of the wellhead was determined by the depth of the hydrate occurrence zone.

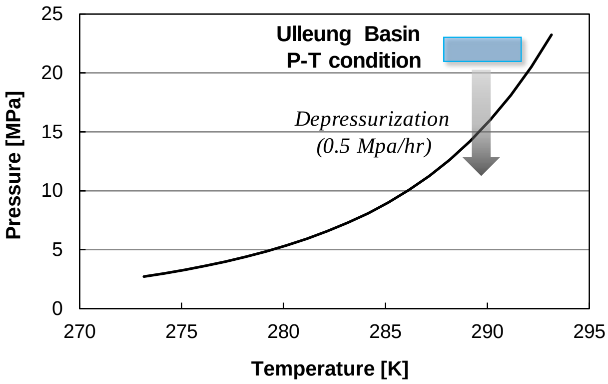

Fig. 1. Initial condition of UBGH2-6

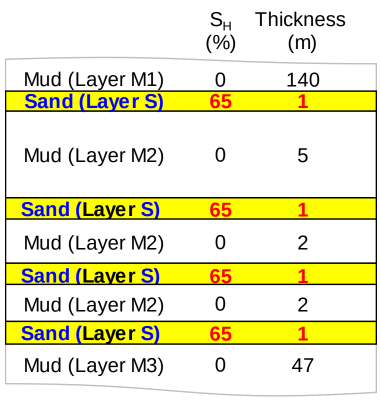

Fig. 2. Initial condition of UBGH2-6

3 SIMULATION APPROACH

3.1 THM Simulator

A coupled thermal-hydraulic-mechanical (THM) simulation developed by Kim et al. (2018) is conducted to evaluate the geomechanical stability of the hydrate-bearing sediments. Three-dimensional model is used to simulate a field-scale, which incorporates the hydrate dissociation; pore fluids flow (water and gas), thermal changes (i.e., latent heat, conduction and advection), and geomechanical response of hydrate-bearing sediments and production wellbore based on the finite differential method, FLAC3D (Itasca 2009). It is assumed that there are only four phases (i.e., gas, water, hydrate, and sediments), and gas solubility and buoyance force are not considered in this study. It is also assumed that fluid phases (i.e., water and gas) are compressible and only flow.

3.2 Description of production well

The schematic design of the production well was modeled as shown in Figure 3. The end depth of the vertical well is 160 m. The wellbore consists of a conductor, casings with diameters of 20" and 13-3/8", a predrilled casing with diameter of 9-5/8", and cement grout for each casing. The screen are located at the innermost area of the wellbore, but mechanical properties are ignored in this study. The stiffness and strength of the predrilled casing in the range from 140 mbsf to 160 mbsf are degraded to 60% of other parts. The details of the well components are summarized in Kim et al. (2018).

3.3 Simulation steps and approach

The simulation included the mail construction sequence such as installation of casing and cement grout, loading weight of production facilities at the seafloor, and subsequent production operation such as a depressurization and gas production. The water pressure at the wellhead is set to decrease at 0.5 MPa/hour and the final target pressure is 9 MPa. The simulation was conducted to evaluate the geomechanical responses of HBS and the stress evolution of the wellbore during the production period of 14 days.

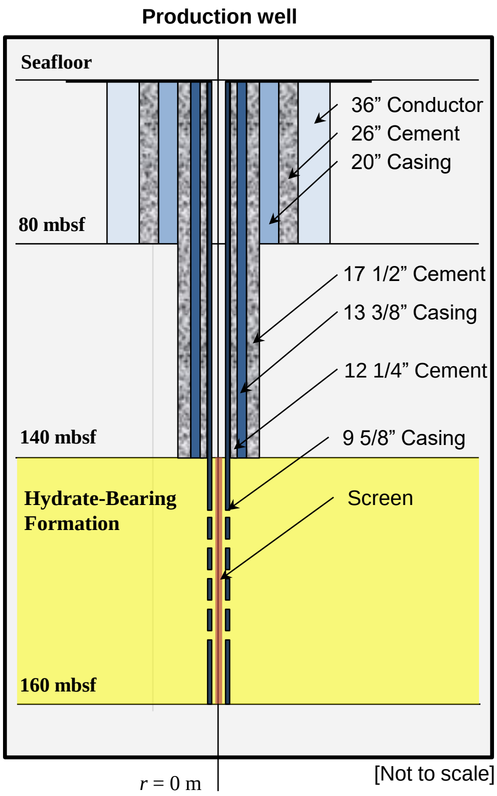

Fig. 3. Schematic design of production wellbore

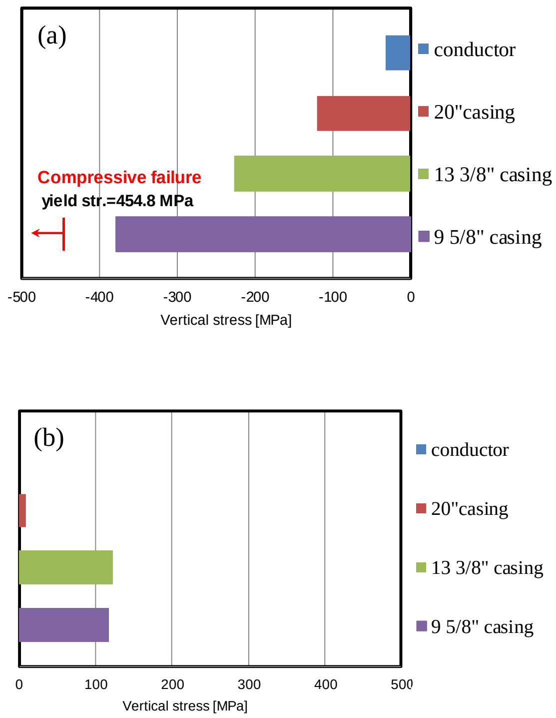

Fig. 5. Maximum axial stress of the wellbore after 14 days. ((a) compressive stress, (b) tensile stress)

4 SIMULATION RESULTS

Figure 4 shows the axial stress (i.e., vertical stress) of the wellbore components along with the vertical length (i.e., depth). A negative value indicates compressive stress whereas a positive value means tensile stress in the casing. A negative value indicates compressive stress whereas a positive value means tensile stress in the casing. After 14 day, the upper load was transferred to compressive stress at the middle part of 13 3/8” casing and pre-drilled casing at 80 mbsf where the end of the conductor and the 20” casing is located.

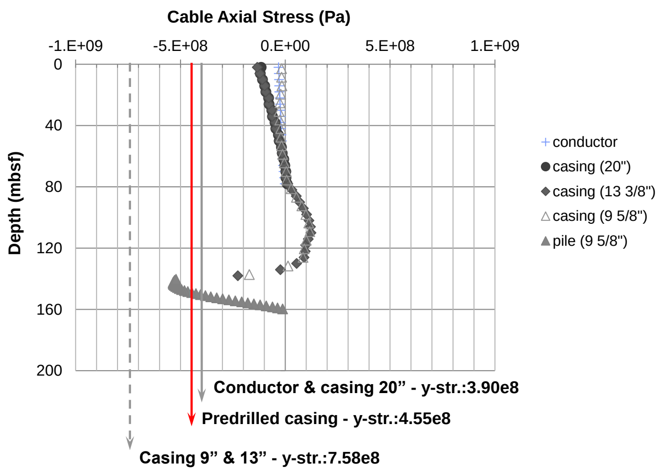

Fig. 4. Axial stress evolution along with the depth after 14 days

Large compressive stress was also induced around the wellhead (i.e., 9 5/8” casing), because the upper and lower sediment was pulled downwards and upwards, resulting in volume compaction as the effective stress increases. As a result, maximum compressive and tensile stress occurred around the wellhead.

Figure 5 shows the maximum axial stress of each wellbore component. The peak compressive stress almost reached the yield strength (i.e., 454.8 MPa) of the pre-drilled casing. Therefore, it is recommended that the allowable bottom hole pressure be set to at most 9 MPa to avoid compressive failure of the given well assembly for 14 days, which is the target period of the pilot production test being planned in Korea.

5 CONCLUSION

This study focused on evaluating stability of the production wellbore and feasibility of the methane hydrate production from methane hydrate-bearing sediments in the Ulleung basin, Korea. The results showed that the peak stress of wellbore was induced at the depressurized zone, and almost reached the yield strength. Nevertheless, it seems to be feasible, if the bottom hole pressure is properly controlled and wellbore component is designed based on the THM simulation results.

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