



Effects of Drilling Mud Properties on Hydrate Dissociation Around Wellbore during Drilling Operation in Hydrate Reservoir

Q. Li^a, Q. Li^{*b}

^a School of Energy Science and Engineering, Henan Polytechnic University, Jiaozuo, China

^b College of Science, Heilongjiang Bayi Agriculture University, Daqing, China

PAPER INFO

Paper history:

Received 18 July 2021

Received in revised form 24 October 2020

Accepted 02 November 2021

Keywords:

Hydrate Dissociation

Hydrate Reservoir

Mud Density

Mud Salinity

Mud Temperature

ABSTRACT

Natural gas hydrate is a potential energy source in the near future, and its commercial development can alleviate the global energy crisis. Disturbance of drilling mud invasion on hydrate reservoir can lead to hydrate dissociation, affecting wellbore stability while drilling in clayey silt hydrate reservoirs. In this work, the coupled thermo-hydro-chemical finite element model was developed, and influences of drilling mud properties on hydrate dissociation were investigated. The obtained results show that the hydrate dissociation range around wellbore widens as the mud temperature increases. The final dissociation range caused by drilling mud invasion nonlinearly increases from 3.83cm to 10.57cm when the mud temperature has increased from 17.25°C to 21.25°C. Therefore, the drilling mud needs to be cooled during preparation in platform. In addition, dissociation range narrows as the bottom-hole pressure increases. Dissociation range decreases from 12.18cm to 7.46cm when the bottom-hole pressure is increased from 14.50MPa to 17.00MPa. Thus, the overbalanced/near-balanced drilling operation is preferred during drilling in hydrate reservoirs, and the underbalanced drilling operation is not recommended. Moreover, the increase of mud salinity exacerbates hydrate dissociation in the near-wellbore region. In view of the prevention of hydrate dissociation in the near-wellbore, it is necessary to confect the drilling mud that with appropriate salinity while drilling in hydrate-bearing sediments.

doi: 10.5829/ije.2022.35.01a.13

1. INTRODUCTION

Natural gas hydrates are ice-like crystalline that is formed by water and gas molecules at low temperature and high pressure [1-3]. Some investigations found that organic carbon stored in gas hydrates is about twice as much that in conventional fossil energy sources [2, 4-6]. Moreover, it is estimated that natural gas hydrates discovered in the South China Sea are about 64 billion tons of oil equivalent [4], which is only about 80% of China's total proved reserves. Natural gas hydrates are bound to be an important potential replacement energy source in China in the near future. Therefore, it is of great significance to carry out numerical and/or experimental investigations related to gas hydrates to ensure energy supply and energy security.

Four strategies are usually used for gas production from hydrate reservoir: (1) Depressurization [7], to decrease the reservoir pressure below the phase equilibrium pressure; (2) Thermal stimulation [8], to heat the reservoir above the phase equilibrium temperature with injection of hot water, hot brine or steam; (3) Thermodynamic inhibitor injection, to inject chemicals [9]; and (4) combination of these above strategies [10]. Among them, the last one appears to be the most efficient. In the past two decades, several field trials have been conducted [11], but most have failed for different reasons. Even so, current research on hydrate development is generally in the stage of theoretical investigation and laboratory exploration, its commercial development still has a long way to go.

Up to now, investigations related to hydrate development mainly focus on the optimization of

*Corresponding Author Institutional Email: B16020083@s.upc.edu.cn
(Q. Li)

production strategies. Li et al. [12] explored the production behavior when horizontal wellbore are used to develop hydrate deposits in the northern South China Sea. The investigation found that current production methods are unable to achieve the goal of commercial development of natural gas hydrates. Wang et al. [13] evaluated the gas production potential of hydrate reservoir in the South China Sea by depressurization. The investigation results showed that the maximum gas production rate was only 9500m³/d, which was far lower than the goal of commercial development offshore. Feng et al. [14] evaluated the effect of well configuration on hydrate dissociation behaviors when depressurization and thermal stimulation methods were simultaneously used. The simulation results indicated that the horizontal wellbore was more efficient for development of hydrate reservoirs. Overall, these studies are beneficial to understand the gas production behavior during development with different strategies. However, almost all studies have proved that no matter which production strategy is adopted, it is difficult to realize its large-scale exploitation. Therefore, if the old development ideas were not broken through, the road to commercial development must be long and difficult.

Accelerating dissociation of gas hydrates in reservoir is the focus for development of natural gas hydrates. However, hydrate dissociation around wellbore while drilling in hydrate reservoirs will worsen the borehole collapse, affecting drilling safety [15]. Therefore, inhibiting excessive hydrate dissociation in the near-wellbore region is an important idea for ensuring wellbore integrity during drilling in hydrate reservoir. However, the reality is that most studies related to hydrate dissociation kinetics concentrate on the effect of inhibitors in drilling fluid on phase equilibrium conditions. Sensitivity analysis of dissociation status of hydrate around wellbore during the drilling operation is scarce now. Fereidounpour and Vatani [16] developed the polyacrylate drilling fluid to prevent hydrate dissociation and wellbore instability caused by disturbance of drilling mud during drilling operation. The experimental results show that the designed drilling fluids can effectively reduce the possibility of hydrate dissociation in the near-wellbore region. Zhao et al. [17] investigated the effect of inhibitors in water-based drilling fluid on hydrate dissociation during drilling operation. They found that all of thermodynamic hydrate inhibitors can affect hydrate dissociation. Moreover, the investigation showed that the combination of 0.1wt% polyvinyl pyrrolidone and 0.5wt% soybean lecithin exhibited the best inhibition effect. Therefore, it is of great engineering significance to carry out investigation on hydrate dissociation around wellbore during drilling in hydrate reservoirs. Moreover, conduction of relevant scientific research can provide theoretical premise for the

design and optimization of the corresponding drilling operation.

In the present work, a numerical simulation model for investigating hydrate dissociation around wellbore during drilling operation is developed. Based on this, influences of mud properties (such as mud density and temperature) on hydrate dissociation caused by drilling mud disturbance are then investigated. The aim of this work is to provide reference for in-depth understanding the mechanism of wellbore instability in hydrate reservoirs.

2. FUNDAMENTAL THEORY

During drilling in hydrate reservoir, mud temperature is usually higher than the initial reservoir temperature. Besides, mud pressure is generally close to the initial pore pressure. In this case, disturbance of drilling mud is detrimental to stability of natural gas hydrates around wellbore, resulting in serious hydrate dissociation. Moreover, the dissociation products of hydrates enter the wellbore and change the bottom-hole pressure, affecting drilling safety [18]. Considering the fact that hydrate dissociation caused by drilling mud disturbance around wellbore is a complex process involving seepage, heat transfer and phase change [19], relevant fundamental theories should be clarified.

2. 1. Mass Conservation Equations

The continuity equations for methane gas, water and hydrate in hydrate reservoir can be expressed by Equations (1), (2) and (3), respectively.

$$-\nabla \cdot (\varphi \rho_g S_g v_g) + m_g + q_g = \frac{\partial(\varphi \rho_g S_g)}{\partial t} \quad (1)$$

$$-\nabla \cdot (\varphi \rho_w S_w v_w) + m_w + q_w = \frac{\partial(\varphi \rho_w S_w)}{\partial t} \quad (2)$$

$$-\nabla \cdot (\varphi \rho_h S_h v_h) - m_h = \frac{\partial(\varphi \rho_h S_h)}{\partial t} \quad (3)$$

where φ , S and ρ indicate porosity (%), saturation (%) and density (kg/m³), respectively; m is the formation rate of hydrate or production rate of dissociation products (kg/s); q represents the source/sink terms of dissociation products (unitless); v is the velocity (m/s); t is time (s). In addition, the subscripts g , w and h represent methane gas, water and hydrate, respectively.

2. 2. Filtration Equations

The seepage of all fluids in the pores follows Darcy's law, which can be expressed as:

$$Q = -\frac{KA\nabla P}{\mu L} \quad (4)$$

where Q is the flow rate (m^3/s); K is the permeability (m^2); P is the pressure (Pa); μ represents the fluid viscosity in reservoir (Ps·s); A is the cross-sectional area of the reservoir (m^2); L is the length of reservoir (m).

Therefore, filtration equations of methane gas and water in hydrate reservoir can be written as the following equations, respectively:

$$\phi S_g v_{rg} = -\frac{K_{rg}}{\mu_g} (\nabla P_g + \rho_g g) \quad (5)$$

$$\phi S_w v_{rw} = -\frac{K_{rw}}{\mu_w} (\nabla P_w + \rho_w g) \quad (6)$$

where g is the gravitational acceleration (m/s^2). The subscripts rw and rg represent the relative value of water and methane gas, respectively.

2.3 Energy Conservation Equation Hydrate dissociation is an endothermic reaction [20], which can affect the reservoir temperature. Besides, heat transfer and thermal convection occurred in the near-wellbore region during drilling operation are also two important factors affecting reservoir temperature. Therefore, the energy conservation equation can be written as

$$\nabla \cdot (\lambda_c \nabla T) - \nabla \cdot (\rho_g v_g H_g + \rho_w v_w H_w) + Q_{in} = \frac{\partial}{\partial t} [(1-\phi)\rho_r H_r + \phi S_h \rho_h H_h + \phi S_g \rho_g H_g + \phi S_w \rho_w H_w] \quad (7)$$

where λ_c is the thermal conductivity of reservoir ($\text{W}/(\text{m}\cdot\text{K})$); H is the enthalpy (J/mol); T is the reservoir temperature (K); Q_{in} is external energy supplement (J).

2.4. Stability of Methane Hydrate Phase equilibrium equation of methane hydrate in Equation (8) is commonly preferred to determine hydrate dissociation or not in fresh water [21].

$$\text{Log}_{10} P_{eq} = 0.034 T_{eq} + 0.0005 T_{eq}^2 + 6.4804 \quad (8)$$

where P_{eq} and T_{eq} are the equilibrium pressure (Pa) and the equilibrium temperature (K), respectively.

The mud salinity is an important factor affecting the stability of natural gas hydrates [22]. Effect of drilling fluid salinity on the equilibrium temperature of methane hydrate can be determined by Equation (9).

$$\Delta T_{eq} = 2335 \cdot \text{Con} / M (100 - \text{Con}) \quad (9)$$

where Con is the mud salinity (wt%); M is the relative molecular weight of inhibitor (unitless).

3. NUMERICAL SIMULATION

3.1. Simulation Model As we all know, drilling operation in hydrate reservoir generally only lasts for a very short time. Hydrate dissociation during drilling in hydrate reservoirs only occurs in the near-wellbore region, so the model size does not need to be particularly large. Figure 1 shows the location and geometry of the investigation model. As shown in Figure 1, the simulation model is a long rectangular cuboid stratum. The cross section of the simulation model in the Y-Z coordinate plane is a square with a side length of 1.0m, the lateral (X-direction) model length is 20.0m; which is sufficient to simulate the hydrate dissociation in the near-wellbore region during drilling operation. In addition, the borehole size is approximately 0.1988m.

During drilling operation, one side (i.e., side A in Figure 1) of the simulation model directly contacts and interacts with the drilling fluid. On the other side (i.e., side B in Figure 1) of the model is the hydrate-bearing sediments far away from the borehole. The simulation model has been divided into 200 elements along its X direction. However, there is only one element in the Y direction and the Z direction, respectively.

3.2 Boundary Conditions As mentioned earlier, reservoir temperature and pore pressure are the two most important factors affecting the stability of natural gas hydrates. Therefore, two boundary conditions of mud temperature and bottom-hole pressure are defined on the left side of the simulation model (i.e., side A in Figure 1). Apart from this, no other boundary conditions are defined for the model.

3.3 Reservoir Properties Generally speaking, reservoir properties can be obtained by the logging data. The reservoir properties at site SH2 of the GMGS-1

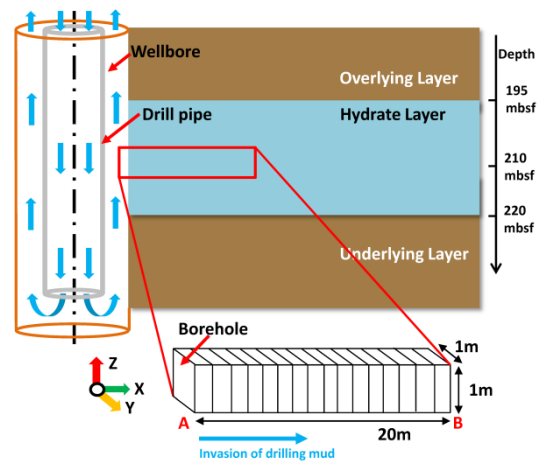


Figure 1. Location and geometry of the investigation model

project have been investigated by some experts. Figure 2 shows some reservoir properties required for investigation herein at site SH2 of the GMGS-1 project.

The exploration results indicate that hydrate reservoir at site SH2 of the GMGS-1 project is located in the depth range of 195mbsf (meaning "meters below the seafloor") to 220mbsf. Herein, the reservoir properties within the investigation model are intended to be represented by that at 210mbsf. Therefore, as can be seen from Figure 2, the reservoir porosity is 55.06%, the thermal conductivity is 1.308 W/(m·K), the hydrate saturation is 40.42%, and the reservoir temperature is 15.25 °C. Besides, some other reservoir properties required to conduct the investigation are displayed in Tables 1, and 2 summarized some properties of drilling mud.

TABLE 1. Other hydrate reservoir properties required for investigation

Property	Value	Unit
Water depth	1232	m
Permeability	4.0	mD
Matrix density	2650	kg/m ³
Pore pressure	15.50	MPa
Water saturations	59.58	%
Capillary pressure parameters: Van-Genuchten model	$S_{ar}=0.24, n=1.84, a=10.0$	

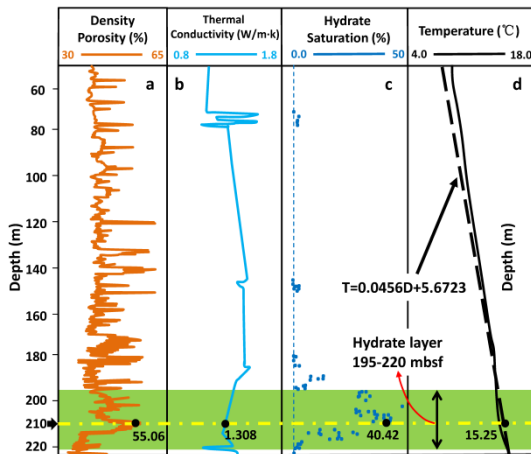


Figure 2. Some reservoir properties at site SH2

TABLE 2. Properties of drilling mud

Property	Value	Unit
Mud temperature	17.25-21.25	°C
Bottom-hole pressure	14.50-17.00	MPa
Mud salinity	0, 15 and 30	wt%
Total drilling time	10800	S

4. RESULTS AND DISCUSSION

4. 1. Disturbance of Drilling Mud on Hydrate Reservoir

Figure 3 shows the reservoir conditions at site SH2 of GMGS-1 project and the phase equilibrium conditions of methane hydrate. As can be seen from Figure 3, natural gas hydrates under reservoir conditions are stable, but changes of reservoir temperature and reservoir pressure caused by mud invasion can result in hydrate dissociation. In other words, changes of reservoir temperature and reservoir pressure in the near-wellbore region are the premise for investigation of hydrate dissociation. Therefore, variation of temperature distribution around wellbore caused by drilling mud invasion is firstly analyzed.

Figure 4 shows the evolution of temperature distribution around wellbore when the drilling mud temperature is 17.25 °C. We can see from Figure 4 that the temperature disturbance range in the near-wellbore region gradually widens during drilling operation, but the disturbance effect gradually weakens. When the drilling operation lasted for 1h (i.e., 60min), the temperature disturbance front reached the position with a distance of 14.50cm from the borehole. However, the temperature

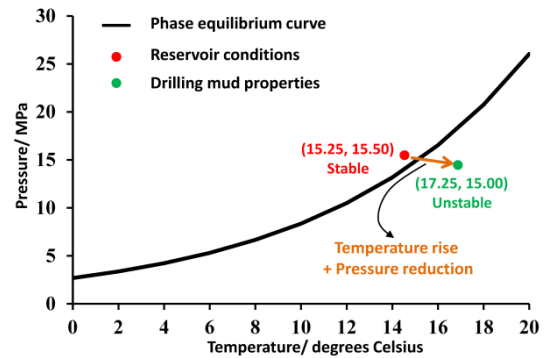


Figure 3. Reservoir conditions at site SH2 of the GMGS-1 project and the phase equilibrium condition

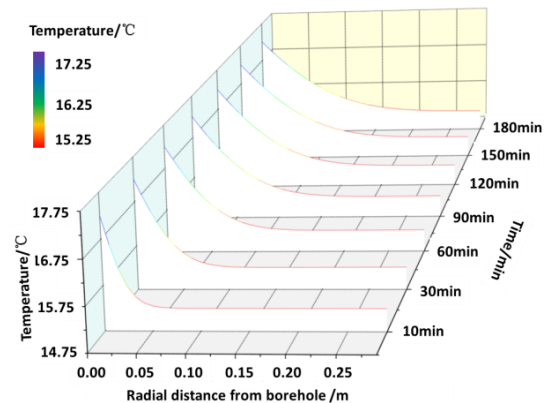


Figure 4. Evolution of temperature distribution in the near-wellbore region when the mud temperature is 17.25 °C

disturbance range is only 22.35cm at the end of drilling operation. The temperature disturbance range during the first third of the drilling operation accounted for 64.88% of that for the entire drilling operation. Therefore, we can infer that if the drilling operation continues, the temperature disturbance range will continue to increase at a gradually decreasing rate.

Figure 5 shows the evolution of pore pressure within the near-wellbore region when the bottom-hole pressure is 15.00MPa. From Figure 5, one can see that the drilling mud invasion disturbs the pore pressure in the near-wellbore region severely. When the drilling operation started less than 2.0h, the pore pressure in almost the entire model had been disturbed by drilling fluid invasion. In this work, we define the situation when mud temperature is higher than the reservoir temperature as the positive temperature difference. In addition, due to mud circulation in wellbore, the mud temperature is usually higher than that of hydrate reservoir. Therefore, only the cases of positive temperature difference are investigated in this work. Figure 6 shows the dissociation range of natural gas hydrate when mud temperature is different.

4. 2 Effect of Mud Temperature on Hydrate Dissociation

Firstly, the basic characteristics of hydrate dissociation around wellbore during drilling operation are analyzed in this section. From Figure 6, one can see that hydrate dissociation range around wellbore gradually widens at a decreasing rate at any mud temperature, which can be clearly illustrated by the decreasing curve slope. Taking the mud temperature of 21.25 °C as an example, dissociation front reached the position of 6.47cm away from wellbore axis after 1 hour of drilling operation. However, the final dissociation front only reached the position of 10.93cm from the wellbore axis. Therefore, it can be inferred that the dissociation range will also continuously widen if the drilling operation continues, but the dissociation rate will

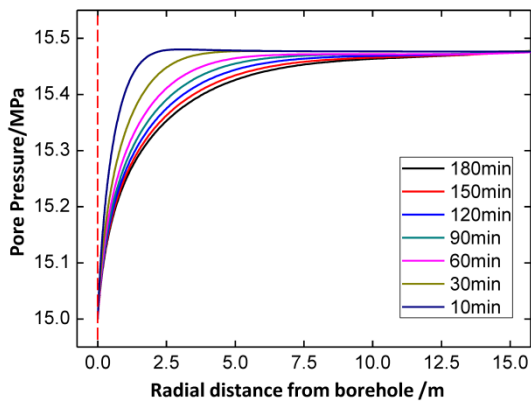


Figure 5. Evolution of pore pressure within the near-wellbore region when the bottom-hole pressure is 15.00MPa

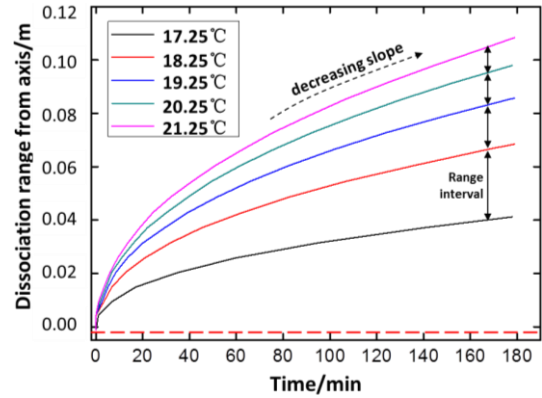


Figure 6. Effect of mud temperature on hydrate dissociation when mud pressure is 15.00MPa

gradually slow down as usual. This is mainly because that hydrate dissociation is an endothermic reaction, and hydrate dissociation can lead to the decrease of reservoir temperature near the dissociation front, hindering the further dissociation. In addition, the dissociation products (i.e., methane gas and water) can increase the pore pressure, which is another important factor hindering the further hydrate dissociation in pores.

Then, effect of mud temperature on hydrate dissociation around wellbore was analyzed. It can be seen from Figure 6 that mud temperature influences hydrate dissociation seriously while drilling in hydrate reservoir, hydrate dissociation range increases with an increase in mud temperature. When the mud temperature is 21.25 °C, the final dissociation range is 10.93cm after drilling operation starts for 3 hours. However, when the mud temperatures are 20.25 °C, 19.25 °C, 18.25 °C and 17.25 °C, the final dissociation ranges are 10.93cm, 10.02cm, 8.81cm, 7.07cm and 3.83cm, respectively. The hydrate dissociation range of the case when the mud temperature is 21.25 °C is 2.76 times the size when the mud temperature is 17.25 °C. The main reason for this is that high positive temperature difference can result in severe heat transfer between the drilling mud and reservoir, and then reservoir temperature within the near-wellbore region will be severely disturbed. The severe disturbance of drilling mud to reservoir temperature results in a wide dissociation range of natural gas hydrate when mud temperature is high. Therefore, the drilling mud should be cooled when it is prepared on the platform, so as to avoid massive dissociation of natural gas hydrates around wellbore.

Moreover, we can also draw the conclusion from Figure 6 that with an increase in mud temperature, the difference in final dissociation range will gradually decrease for the same temperature difference (i.e., 1 °C herein). This can be clearly seen by the decreasing intervals between each curve in Figure 6. The decreasing intervals show the decreasing effect of mud temperature

on an increase in hydrate dissociation range. In the future, effect of mud temperature on borehole collapse can be investigated. Besides, based on investigation of borehole collapse in hydrate reservoir, engineering measures for reducing the drilling risk can be proposed for mud temperature.

4. 3. Effect of Mud Density on Hydrate Dissociation

As we all know, the bottom-hole pressure can be directly simplified as the value obtained by multiplying mud density by reservoir depth. Therefore, in this section, drilling mud density is directly replaced by bottom-hole pressure, and its influence on hydrate dissociation around wellbore is discussed. Figure 7 displays the effect of bottom-hole pressure (drilling mud density) on hydrate dissociation within the near-wellbore region. As can be seen from Figure 7, hydrate dissociation around wellbore will gradually weaken with an increase in bottom-hole pressure (drilling mud density). When the bottom-hole pressure is 14.50MPa, the final dissociation range is 12.18cm. Such violent hydrate dissociation can pose a great threat to the strength of reservoir around wellbore, which is not conducive to maintaining the stability of borehole. However, when the bottom-hole pressure increases to 17.00MPa, the final dissociation range is only 7.46cm, which is only about 61.25% of that when bottom-hole pressure is 14.50MPa. According to investigation conducted by Li et al. [22], this is mainly because when the mud density is small, the pore pressure at the same location in the near-wellbore region around wellbore is relatively low. For the same ambient temperature (i.e., reservoir temperature), lower ambient pressure (i.e., pore pressure) is not conducive to the stability of natural gas hydrates in pores.

In order to prevent uncontrolled hydrate dissociation, the research results can provide the reasonable suggestion for the design of drilling fluid density used in hydrate reservoir. It can be seen from the investigation results that high-density drilling mud is preferred for

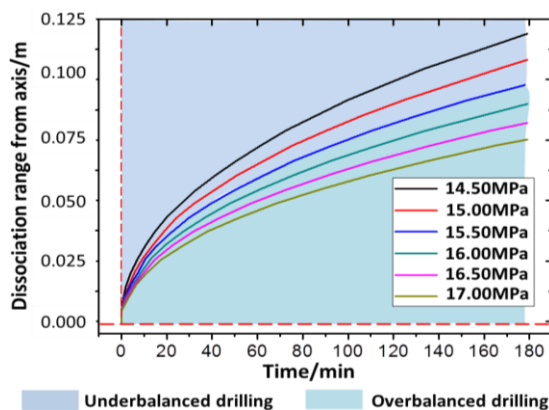


Figure 7. Effect of mud density on hydrate dissociation when the mud temperature is 21.25°C

maintaining wellbore stability while drilling in the hydrate reservoirs. That is to say, in order to prevent serious borehole collapse caused by hydrate dissociation, the overbalanced drilling technology or near-balance drilling technology are recommended during drilling in hydrate reservoir. However, the underbalanced drilling operation can result in serious hydrate dissociation in clayey silt hydrate reservoirs, which may lead to the borehole collapse with the near-wellbore region. Therefore, the underbalanced drilling technology is not recommended during drilling hydrate reservoirs. Furthermore, in the future, method for determination of the safe mud weight window with considering hydrate dissociation can be explored by mechanical experiment.

4. 4. Effect of Inhibitor Concentration on Hydrate Dissociation

Hydrate inhibitors are usually used to control hydrate formation in borehole annulus or submarine pipeline for flow safety. Herein, we want to investigate the influence of inhibitor on hydrate dissociation, not on hydrate formation. NaCl is one of the most commonly mentioned inhibitors. The influence of NaCl solution concentration on hydrate dissociation around wellbore is investigated in this section. Therefore, inhibitor concentration can be considered as the mud salinity here. The effect of inhibitor on hydrate dissociation is essentially achieved by affecting its dissociation kinetic conditions. However, it is sometimes difficult to directly determine the phase equilibrium conditions for any inhibitor concentrations. Just as Figure 8 shows, a method for quantitatively determining the effect of inhibitor on phase equilibrium conditions of methane hydrate is presented. First of all, it is necessary to determine the decrease in phase equilibrium temperature caused by inhibitor addition according to Equation (7). Then, the phase equilibrium pressure can be determined by combining the calculated phase equilibrium temperature by Equation (8) through

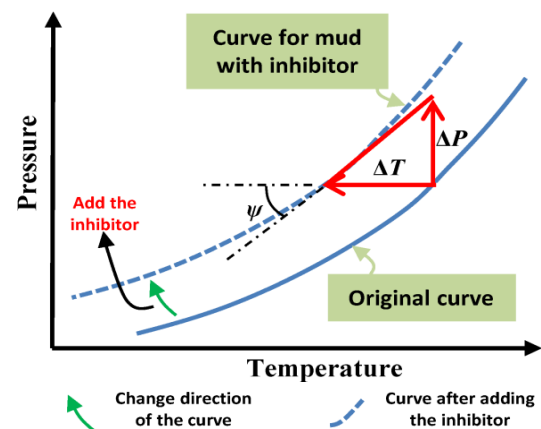


Figure 8. Method for determining effect of inhibitor (NaCl) on phase equilibrium conditions

trigonometric function. By this method, the phase equilibrium conditions for any inhibitor concentrations can be determined rapidly.

Figure 9 displays the effect of inhibitor concentration on hydrate dissociation during drilling in hydrate reservoir. As can be seen from Figure 9, hydrate dissociation occurs more and more violently with an increase in inhibitor concentration. The final hydrate dissociation range is only about 3.83cm when the inhibitor concentration is 0wt% (i.e., fresh water is used as the drilling mud). However, the dissociation range reaches 8.72cm when the inhibitor concentration has increased to 30wt%, which is 2.28 times the dissociation range when fresh water is used as the drilling mud. The influence mechanism of inhibitor concentration on hydrate dissociation around wellbore in drilling operation has been revealed in literature [21]. According to Zhao et al. [21], we know that the main reason for this is that inhibitors can reduce the range of the stable area (i.e., the upper left part of Figure 3) in the hydrate phase diagram, making the formation of natural gas hydrates more difficult. On the contrary, addition of inhibitor can expand the range of unstable area, which makes the hydrate dissociation occurs more easily.

In spite of the fact that proper increase in inhibitors in the drilling mud can inhibit the formation of natural gas hydrates within the wellbore, which is beneficial to well control during the drilling operation. However, excessive concentrations of inhibitors can not only lead to violent hydrate dissociation and severe borehole collapse, but also may cause malignant corrosion of the casing string and affect subsequent operations. Therefore, a reasonable inhibitor concentration should be proposed according to the requirements of drilling operation, rather than an arbitrary concentration. In addition, in the future, effect mechanism of different hydrate inhibitor can be experimentally explored to facilitate the optimization of inhibitor concentration.

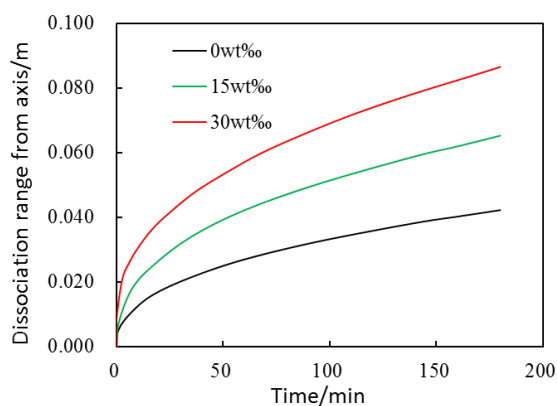


Figure 9. Effect of inhibitor concentration in drilling mud on hydrate dissociation when the mud temperature and bottom-hole pressure are 17.25°C and 15.00MPa respectively

5. CONCLUSIONS

Borehole collapse caused by hydrate dissociation in drilling operation endangers drilling safety. In this study, dissociation characteristics of natural gas hydrates around wellbore in drilling operation was explored with finite element model, and the influence of various factors on hydrate dissociation was also investigated. The obtained results demonstrate that stability of gas hydrates in near-wellbore region can be affected by drilling mud invasion through disturbing reservoir temperature and pore pressure. In drilling operation, hydrate dissociation weakens with an increase in mud density. However, an increase in drilling fluid temperature and inhibitor concentration in drilling fluid will aggravate the dissociation of gas hydrates around wellbore. Therefore, in order to weaken the influence of uncontrollable hydrate dissociation on borehole stability during drilling operation, it is effective to cool the drilling fluid or increase the drilling mud density. Besides, adding hydrate stabilizer to drilling fluid or reducing the inhibitor concentration in drilling fluid is also a desired method.

6. ACKNOWLEDGEMENTS

This work is supported by the program for Postdoctoral Program of Henan Polytechnic University (712108/210).

7. REFERENCES

1. Dvoynikov, M. V., Nutskova, M. V., Blinov, P. A. "Developments Made in the Field of Drilling Fluids by Saint Petersburg Mining University" *International Journal of Engineering, Transactions A: Basics*, Vol. 33, No. 4, (2020), 702-711. DOI: 10.5829/IJE.2020.33.04A.22
2. Klar, A., Soga, K., Ng, M. Y. A. "Coupled deformation-flow analysis for methane hydrate extraction" *Géotechnique*, Vol. 60, No. 10, (2010), 765-776. DOI: 10.1680/geot.9.P.079-3799
3. Shankar, U., Sain, K., Riedel, M. "Assessment of gas hydrate stability zone and geothermal modeling of bsr in the Andaman Sea" *Journal of Asian Earth Sciences*, Vol. 79, (2014), 358-365. DOI: 10.1016/j.jseas.2013.10.021
4. Lu, S. M. "A global survey of gas hydrate development and reserves: Specifically in the marine field" *Renewable & Sustainable Energy Reviews*, Vol. 41, No. 4, (2015), 884-900. DOI: 10.1016/j.rser.2014.08.063
5. Gai, X. R., Sánchez, M. "A geomechanical model for gas hydrate-bearing sediments" *Environmental Geotechnics*, Vol. 4, No. 2, (2017), 143-156. DOI: 10.1680/jenge.15.00050
6. Yan, C., Cheng, Y., Li, M., Han, Z., Zhang, H., Li, Q., Teng, F., Ding, J. "Mechanical experiments and constitutive model of natural gas hydrate reservoirs" *International Journal of Hydrogen Energy*, Vol. 42, No. 31, (2017), 19810-19818. DOI: 10.1016/j.ijhydene.2017.06.135
7. Ahmadi, G., Ji, C. A., Smith, D. H. "Production of natural gas from methane hydrate by a constant downhole pressure well" *Energy Conversion and Management*, Vol. 48, No. 7, (2007), 2053-2068. DOI: 10.1016/j.enconman.2007.01.015

8. Yao, Y., Wei, M., Kang, W. "A review of wettability alteration using surfactants in carbonate reservoirs" *Advances in Colloid and Interface Science*, Vol. 294, (2021), 102477. DOI: 10.1016/j.cis.2021.102477
9. Liu, X., Jiang, R., Li, J., Huang, W. "Characteristics of Shale Gas Reservoir in Jiyang Depression and its Significance in Drilling and Exploitation" *International Journal of Engineering, Transactions B: Applications*, Vol. 33, No. 8, (2020), 1677-1686. DOI: 10.5829/IJE.2020.33.08B.27
10. Poplygin, V. V., Pavlovskaja E. E. "Investigation of the Influence of Pressures and Proppant Mass on the Well Parameters after Hydraulic Fracturing" *International Journal of Engineering, Transactions A: Basics*, Vol. 34, No. 4, (2021), 1066-1073. DOI: 10.5829/IJE.2021.34.04A.33
11. Wang, Y., Lang, X., Fan, S., Wang, S., Yu, C., Li, G. "Review on enhanced technology of natural gas hydrate recovery by carbon dioxide replacement" *Energy & Fuels*, Vol. 35, No. 5, (2021), 3659-3674. DOI:10.1021/acs.energyfuels.0c04138
12. Li, G., Moridis, G. J., Zhang, K., Li, X. S. "Evaluation of gas production potential from marine gas hydrate deposits in shenhu area of south china sea" *Energy & Fuels*, Vol. 24, No. 11, (2010), 6018-6033. DOI: 10.1021/ef100930m
13. Wang, Y., Feng, J, Li, X., Zhang, Y., Li, G. "Evaluation of gas production from marine hydrate deposits at the GMGS2-site 8, pearl river mouth basin, South China Sea" *Energies*, Vol. 9, No. 3, (2016), 222. DOI: 10.3390/en9030222
14. Su, Z., Li, H., Wu, N., Yang, S. "Effect of thermal stimulation on gas production from hydrate deposits in shenhu area of the south china sea" *Science China Earth Sciences*, Vol. 56, No. 4, (2013), 601-610. DOI: 10.1007/s11430-013-4587-4
15. Zhao, X., Qiu, Z., Gao, J., Ren, R., Li, J., Huang, W. "Mechanism and effect of nanoparticles on controlling fines migration in unconsolidated sandstone formations" *SPE Journal*, Vol. 26, No. 1, (2021), 1-13. DOI: 10.2118/204474-PA
16. Fereidounpour, A., Vatani, A. "Designing a Polyacrylate Drilling Fluid System to Improve Wellbore Stability in Hydrate Bearing Sediments" *Journal of Natural Gas Science and Engineering*, Vol. 26, (2015), 921-926. DOI: 10.1016/j.jngse.2015.06.038
17. Zhao, X., Qiu, Z., Zhao, C., Xu, J., Zhang, Y. "Inhibitory effect of water-based drilling fluid on methane hydrate dissociation" *Chemical Engineering Science*, Vol. 199, No. 18, (2019), 113-122. DOI: 10.1016/j.ces.2018.12.057
18. Tabatabaee Moradi, S.S., Nikolaev, N. I. "Study of Bonding Strength at Salt-cement Interface During Cementation of Salt Layers" *International Journal of Engineering, Transactions B: Applications*, Vol. 34, No. 2, (2021), 581-586. DOI: 10.5829/IJE.2021.34.02B.32
19. Chen, D. C., Yao, Y., Fu, G., Meng, H. X., Xie, S. X. "A new model for predicting liquid loading in deviated gas wells" *Journal of Natural Gas Science and Engineering*, Vol. 34, (2016), 178-184. DOI: 10.1016/j.jngse.2016.06.063
20. Leusheva, E., Morenov, V., Tabatabaee Moradi S. "Effect of Carbonate Additives on Dynamic Filtration Index of Drilling Mud" *International Journal of Engineering, Transactions B: Applications*, Vol. 33, No. 5, (2020), 934-939. DOI: 10.5829/IJE.2020.33.05B.26
21. Zhao, X., Qiu, Z., Zhao, C., Xu, J., Zhang, Y. "Inhibitory effect of water-based drilling fluid on methane hydrate dissociation" *Chemical Engineering Science*, (2019) Vol. 199, 113-1232. DOI: 10.1016/j.ces.2018.12.057
22. Li, Q., Liu, L., Yu, B., Guo, L., Shi, S., Miao, L. "Borehole enlargement rate as a measure of borehole instability in hydrate reservoir and its relationship with drilling mud density". *Journal of Petroleum Exploration and Production*, Vol. 11, No. 3, (2021), 1185-1198. DOI: 10.1007/s13202-021-01097-2

Persian Abstract

چکیده

هیدرات گاز طبیعی یک منبع انرژی بالقوه در آینده نزدیک است و توسعه تجاری آن می تواند بحران جهانی انرژی را کاهش دهد. اختلال در تهاجم گل حفاری به مخزن هیدرات می تواند منجر به تفکیک هیدرات شود که بر پایداری چاه در حین حفاری در مخازن هیدرات سیلت رسی تأثیر می گذارد. در این کار، مدل همان محدود حرارتی- هیدروشمیایی جفت شده توسعه داده شد و تأثیرات خواص گل حفاری بر تفکیک هیدرات مورد بررسی قرار گرفت. نتایج بدست آمده نشان می دهد که با افزایش دمای گل، محدوده تفکیک هیدرات در اطراف چاه گسترش می یابد. محدوده تفکیک نهایی ناشی از تهاجم گل حفاری به طور غیرخطی از 3.83 سانتی متر به 10.57 سانتی متر افزایش می یابد زمانی که دمای گل از 17.25 درجه سانتیگراد به 21.25 درجه سانتیگراد افزایش می یابد. بنابراین، گل حفاری باید در حین آماده سازی در سکو خنک شود. علاوه بر این، با افزایش فشار سوراخ پایین، محدوده تفکیک باریک می شود. هنگامی که فشار سوراخ پایین از 14.50 مگاپاسکال به 17.00 مگاپاسکال افزایش می یابد، محدوده تفکیک از 12.18 سانتی متر به 7.46 سانتی متر کاهش می یابد. بنابراین، عملیات حفاری بیش از حد متعادل/تقریباً متعادل در حین حفاری در مخازن هیدرات ترجیح داده می شود و عملیات حفاری متعادل توصیه نمی شود. علاوه بر این، افزایش شوری گل باعث تشدید تفکیک هیدرات در منطقه نزدیک به چاه می شود. به منظور جلوگیری از تفکیک هیدرات در حفره نزدیک چاه، لازم است هنگام حفاری در رسوبات هیدرات دار، گل حفاری را با شوری مناسب مخلوط کرد.
