LABORATORY SIMULATION OF NATURAL GAS HYDRATE FORMATION AND LOW DISTURBANCE DRILLING

by

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Obtaining real natural gas hydrate pressure-retaining samples is challenging, necessitating the study of in-situ condition preserved coring (ICP-Coring) technology. In this paper, we simulated the in-situ formation of natural gas hydrate natural gas hydrate using a high pressure cooling method within a self-developed formation environment simulation chamber. Drilling experiments were conducted to examine the influence of drilling parameters on low disturbance drilling processes. Our findings indicate that the feed rate of the drill pipe primarily affects the force magnitude on the drill pipe, while the rotational speed of the drill pipe significantly impacts the stability of this force, with slightly higher rotational speeds resulting in less disturbance.

Key words: *natural gas hydrate, in-situ formation, low disturbance drilling, in-situ condition preserved coring,*

Introduction

To obtain authentic natural gas hydrate (NHS) samples, various types of NHS coring techniques have been investigated internationally [1-3]. Despite these efforts, current in-situ pressure-preserved and temperature preserved coring technologies remain underdeveloped. Some existing coring equipment can perform pressure-preserved coring, but their pressure-retaining capacity has not exceeded 70 MPa [4]. The thermal insulation technology is still lacking, causing the samples to decompose and distort due to temperature changes. During the process of transferring samples from the seafloor to the deck, maintaining in-situ conditions using temperature and pressure-preserved transfer apparatus poses significant challenges. Consequently, obtaining genuine samples for laboratory analysis remains difficult. To address these challenges, this study independently developed an NHS formation environment simulation chamber, replicate the in-situ conditions of NHS in the laboratory, enabling the preparation of samples and the study of their basic physical properties. Additionally, it allows for the simulation of the NHS drilling and coring process, thereby providing the essential experimental apparatus required for the investigation of low disturbance ITP-Coring technology.

Huang *et al.* [5] simulated the formation and drilling process of NHS using a self-developed NHS drilling apparatus. They analyzed the effects of drilling fluid temperature and

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circulation rate on the dissociation characteristics of NHS around the wellbore. However, their experimental apparatus was small and not comprehensive enough to fully simulate the drilling process. Yu*et al.* [6] used a sand-pack model apparatus to simulate the decomposition of NHS, studying the factors influencing NHS dissociation and gas intrusion during drilling. The results indicated that the dissociation rate of hydrates and gas production are affected by drilling fluid temperature and hydrate saturation. But this approach may overlook the complex geological conditions encountered during actual drilling operations. Due to the limitations of experimental conditions, there are fewer laboratory studies on NHS drilling, with numerical simulations primarily used to model the property changes of NHS formations during the coring process. Wei *et al.* [7] used Abaqus finite element software to simulate the drilling and coring process in the complex formation of subsea NHS, determined the range of low disturbance cores in hydrate reservoirs, and revealed the intrinsic relationship between the disturbance rate of sediment and hydrate cores and the drilling pressure and rotational speed of the coring bit. However, the disturbance behavior under different types of reservoirs still needs further study. Duan *et al.* [8] studied the distribution and change of temperature field of sampling drill bit when breaking rock in NHS formation, and analyzed the distribution law of borehole temperature rise and the influence of sampling process parameters on the temperature rise of rock formation, but some simplified assumptions on the model may lead to some differences between the simulation results and the real situation. However, the 1-D model may have limitations in capturing the complex flow characteristics in 3-D space. Previous researchers have made substantial contributions to simulating NHS formation and studying the disturbances caused by temperature, pressure, and drilling parameters during the drilling process. However, the existing in-laboratory simulations of the coring process are not comprehensive enough to meet the research needs of low disturbance ITP-Coring techniques. Additionally, the results of numerical simulations can only serve as a reference for field experiments. To address these limitations, we investigate the effect of drilling parameters on low disturbance coring under laboratory conditions using a newly developed NHS formation environment simulation chamber.

Experimental apparatus

In this study, an NHS generation environment simulation chamber was independently developed, as shown in fig. 1. The experimental apparatus consists of NHS simulation system, drilling system, temperature control system, gas pressure control system and data acquisition system. The operating pressure of the apparatus ranges from 0-30 MPa, and the operating temperature ranges from −15 °C to 90 °C. The NHS simulation system consists of a high pressure vessel with sensors for temperature and pressure, with a volume of 160 L. The vessel is divided into five horizontal layers of the same volume, each containing 16 temperature sensors and two pressure sensors, with air inlet at the bottom of the vessel and air outlet at the top. The drilling system is used to simulate the low disturbance drilling process, which consists of bracket, rotating apparatus, motor, and drilling pipes. We have maintained a good sealing by the special threaded structure, so that the reaction vessel will not leak pressure during the drilling process. The drilling system has a feed rate range of 0-0.1 m per minute, a maximum drilling depth of 570 mm, and a rotational speed range of 0-200 rpm. During the drilling process, the torque and depth of the drill pipe can be measured using torque and displacement sensors. The gas pressure control system regulates CH_4 gas to enter the vessel at a specific pressure, and a back-pressure apparatus ensures that the vessel pressure does not exceed the maximum limit. The temperature control system adjusts the water temperature within the vessel using a water bath. The data acquisition system integrates temperature, pressure, and mechanical sensors, enabling real-time monitoring of temperature and pressure changes within the vessel, and records gas consumption and outlet volume to calculate the amount of hydrate formation. Additionally, a balance and gas-flow meter are used to measure the mass of liquid and gas produced from the vessel, respectively.

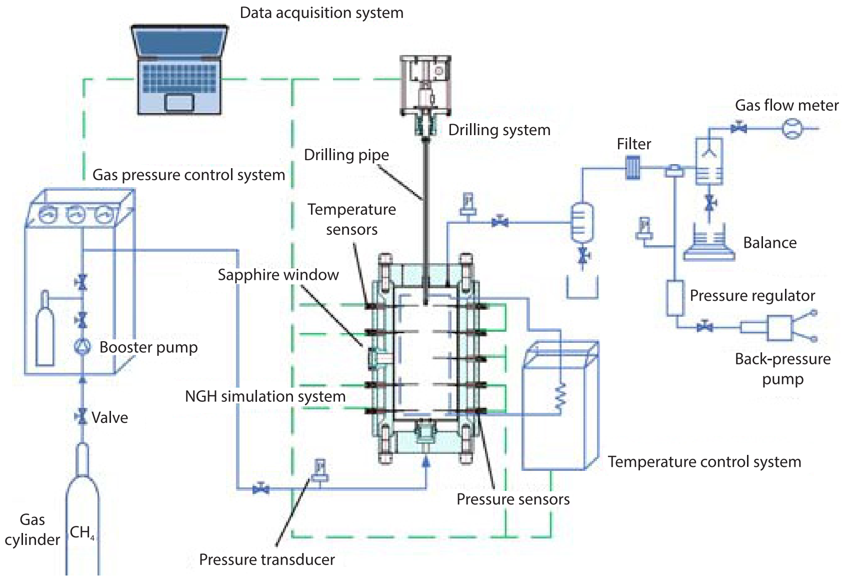

Figure 1. The NHS generating environment simulation chamber

Experimental procedures

The NHS tends to form hydrates under high pressure and low temperature conditions. Therefore, this experiment utilizes a high pressure cooling method and excess gas to induce NHS formation [9]. To accelerate the hydrate formation rate, we prepared a catalyst solution with a concentration of 0.04% by mixing deionized water with 99% pure sodium dodecyl sulfate (SDS) powder [10, 11]. The solution was then uniformly mixed with 180 kg of 16-26 mesh quartz sand and layered into the reaction vessel. The vessel was evacuated to a vacuum state using a vacuum pump, and 99.99% pure CH_4 gas was injected until the pressure reached 10 MPa. Once the pressure stabilized, the temperature was raised to 20 °C, and then start cooling to induce hydrate production.

Once the pressure and temperature in the high pressure vessel stabilized, indicating that NHS formation has become stable, the drilling experiment will commence. Initially, three different feed rates were set at a rotational speed of 50 rpm: 10 mm per minute, 30 mm per minute, and 50 mm per minute, to study the impact of feed rate on low disturbance coring. Subsequently, at a feed rate of 50 mm per minute, four different rotational speeds were set: 20 rpm, 50 rpm, 100 rpm, and 150 rpm, to investigate the effect of rotational speed.

Results and discussion

Pressure and temperature variations in the in-situ NHS formation environment

The pressure variations at ten different measurement points during the formation of NHS are shown in fig. 2(a). During the experiment, signal stagnation was observed at measurement points 6 and 10, which may be attributed to the formation of a dense film of NHS around the sensors [12]. This filmlikely envelops the sensor, obstructing it from accurately measuring the pressure changes within the vessel. In Stage I, the temperature control system is lowering the temperature inside the container, and no hydrate formation occurs. Stage II marks the onset of substantial hydrate formation. Once the temperature inside the vessel drops below the equilibrium temperature, CH_4 gas is significantly consumed, causing the pressure to rapidly decrease from 10.18-3.74 MPa. Stage III involves secondary pressure supplementation, where the pressure inside the vessel is increased to 8.21 MPa, allowing hydrate formation continue. In Stage IV, hydrate formation continues, consuming a significant amount of CH_4 gas, and the pressure gradually stabilizes as the reaction rate slows down. However, occasional rises and fluctuations in the pressure curve indicate that hydrate decomposition is occurring. Hydrate formation and decomposition influence each other, eventually reaching a dynamic equilibrium. Stage V sees the pressure curve stabilizing and the formation rate reaching a steady-state.

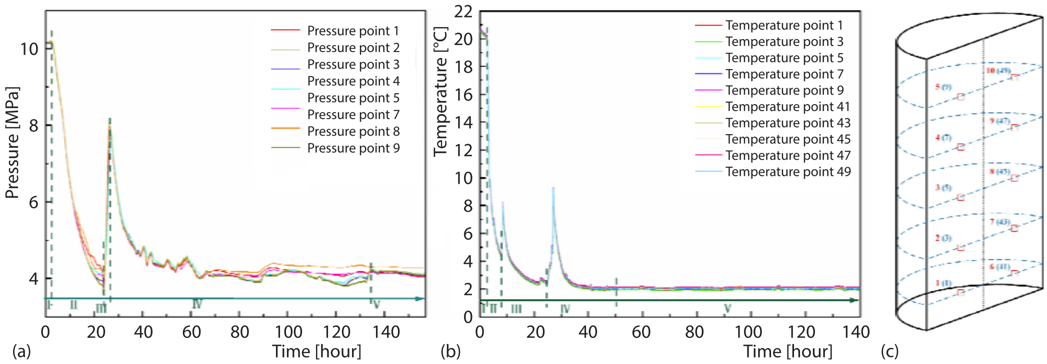

Figure 2. Pressureand temperature changes at different measuring points during NHS formation; (a) pressure changes, (b) temperature changes, and (c) locations of different measurement points (red points represent pressure measuring points, blue points represent temperature measuring points)

The temperature variations at ten different measurement points during the formation of NHS are shown in fig, 2(b). In Stage I, the temperature control system begins operating, and the temperature drops slowly. Stage II is the initial phase of hydrate formation, where hydrates begin to form. However, the exothermic nature of NHS formation releases heat, which slows down the cooling rate of the temperature control system. Stage III corresponds to the rapid hydrate formation stage. During this stage, hydrate formation occurs at a fast rate, generating a significant amount of heat. This heat generation exceeds the capacity of the temperature control system, resulting in a rise in the internal temperature of the vessel. As the hydrate formation rate gradually decreases, the temperature control system begins to effectively lower the internal temperature of the vessel again, bringing it back under control. Stage IV involves thesecondary pressurization of the vessel, which promotes further hydrate formation and releases heat,similar to Stage III. Stage V sees the hydrate formation and decomposition rates reach a dynamic balance, leading to stable hydrate formation. Finally, at the end of the experiment, hydrates were observed through the sapphire window, as shown in fig. 3.

Effect of various drilling parameters on disturbance in low disturbance drilling

The working principle of the NHS corer involves storing the core in an in-situ condition preserved chamber inside the drill pipe, using a special drill bit. During the coring process, fluctuations in the pressure on the drill pipe can cause varying degrees of disturbance to the internal core. Therefore, studying drilling parameters is of great significance for achieving low disturbance coring. At a rotational speed of 50 rpm, the changes in the drilling pipe's force under different feed rates are shown in fig. 4(a). It can be observed that when the rotational speed is constant, the pressure on the drilling pipe increases with the increase in feed rate. At a feed rate of 30 mm per minute, the pressure fluctuations on the drilling pipe are relatively small. This phenomenon may be explained by the fact that as the feed rate increases, the drill bit needs to cut more hydrate simultaneously. This requires the back end of the drill pipe to exert greater cutting force and drilling pressure, resulting in the drill pipe being subjected to higher overall pressure. As shown in fig. 4(b), the variation of pressure on the drill pipe at different rotational speeds was obtained at a feed rate of 50 mm per minute. It was observed that at low rotational speeds, the pressure on the drill pipe was greater than at other speeds. This may be due to the low rotational speed of the drill pipe, resulting in insufficient cutting force on the hydrates and low rock-breaking efficiency, thereby increasing the frictional force.The pressure exerted on the drill pipe fluctuates greatly at 50 rpm and 150 rpm, and is most stable at 100 rpm.

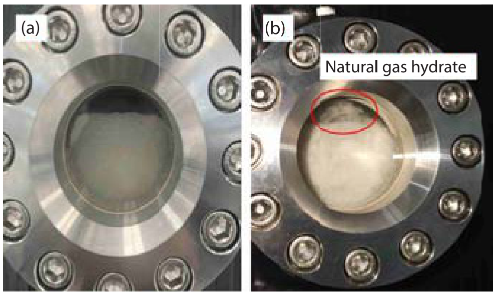

Figure 3. Comparison of the external window before and after the experiment; (a) window before the experiment and (b) window after the experiment

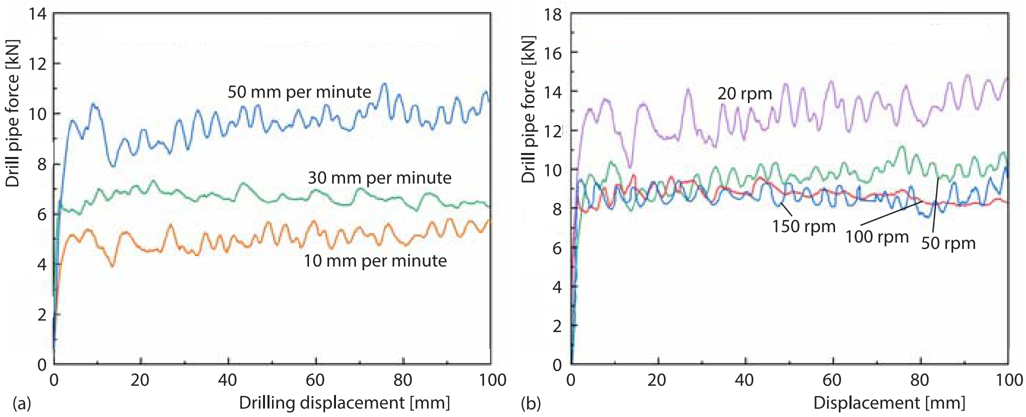

Figure 4. Variation of force on drill pipe with different parametersduring the drilling; (a) feed rates and (b) rotational rates

The change in force on the drill pipe reflects the change in stress within the hydrate reservoir to a certain extent. Pressure and stress are directly proportional to each other. Based on the previous discussion, it can be concluded that the feed rate primarily affects the stress magnitude on the hydrate core. When the feed rate is constant, a higher rotational speed increases the cutting rate of the drill bit, which reduces stress concentration and makes the stress on the core surface more uniform and sustained. However, if the rotational speed is too high, it will generate more frictional heat, which may cause the hydrate cores to decompose due to the increased temperature. Thus, it can be concluded that the rotational speed mainly affects the stability of stress changes in the hydrate core.

Conclusion

In this paper, the in-situ formation and coring process of NHS is simulated using a self-developed NHS formation environment simulation chamber. The influence of drilling parameters on the disturbance of NHS samples is analyzed. It can be concluded that the feed rate primarily affects the pressure on the drill pipe and the stress on the core. Conversely, the rotational speed mainly affects the stability of the force on the drill pipe. A too low rotational speed increases the pressure on the drill pipe, while a slightly higher rotational speed stabilizes the force on the drill pipe, resulting in lower disturbance. Compared with offshore experiments, simulated coring in the laboratory can provide valuable guidance for real drilling and coring operations.

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