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Proceedings of The Fourth International Technical Symposium on Deepwater Oil and Gas Engineering
Deepwater is rich in oil, gas and hydrate resources, where the exploitation is known as highly difficult with high risk, high investment and high return. As the exploration and development of deepwater oil, gas and hydrate resources grow, many special technical problems are encountered, and extensive attention from industry and academic is attracted.

In order to promote the exchange and cooperation between global scholars and promote the technological progress of deepwater oil, gas and hydrate development, the *International Technical Symposium on Deepwater Oil and Gas Engineering & the International Youth Forum on Gas Hydrate (DWOG-Hyd)* series conference was founded in 2017. The first three conferences were held in Haikou and Qingdao in China from 2017 to 2019, and more than seven hundred people participated. The participants were mainly technical experts and scholars from industries and universities in China, the USA, the UK, Russia, Norway, Singapore, Canada and other countries. The DWOG-Hyd conference has formed important international influence in the field of deepwater oil, gas and hydrate exploitation research.

The fourth DWOG-Hyd conference was held on December 20 to 21, 2021, onsite in Qingdao and online, hosted by China University of Petroleum (East China), CNPC Engineering Technology R&D Company Ltd, Journal of Hydrodynamics and other institutes. The DWOG-Hyed 2021 focused on cutting-edge areas such as natural gas hydrate drilling and production, carbon dioxide storage, deepwater drilling and completion, oil and gas flow assurance and emerging hydrate-based technologies. A total of more than two thousand person-times participated both onsite and online. Participants are from ten countries including China, the USA, the UK, Canada, Brazil, Norway and Singapore, etc. Seventeen plenary speeches and seventy-seven session speeches were presented. One hundred and twenty-seven abstracts/papers were received, and forty papers were selected to publish in the proceedings.

In this book, there are nine papers for deepwater drilling and completion, thirteen papers for natural gas hydrate production, nine papers for deepwater oil and gas flow assurance and nine papers for fundamentals and emerging technologies of clathrate hydrate. A large number of new findings and novel ideas were reported.
We wish the DWOG-Hyd conference and the proceedings to be helpful to accelerate the exploration and development of deepwater oil, gas and hydrate resources.

January 2022

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Deepwater Drilling and Completion
Prospects of Special Ocean Engineering Equipment Application in Chinese Marine NGH Trial Production

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Abstract. Natural gas hydrate (NGH) is a potential alternative clean energy. According to its formation conditions such as high pressure and low temperature, the geological survey results indicate that there are abundant NGH resources buried in both the sediments of the permafrost and ocean of China, leading to the great natural advantages for the mineral industrialization. Considering the determining factors such as resource distribution, trial production progress, as well as the gap between maximum daily production rate and commercial production critical value, it is believed that the deep water especially in South China Sea will be the main battlefield for the cause of Chinese NGH development in a short term, whose specific operations always depend on the ocean engineering equipment. Based on the characteristics of NGH occurrence and its phase transitions in the marine weakly cemented shallow layers, this research summarizes and analyzes the application status of special ocean engineering equipment, such as floating body and underwater devices, applied in NGH trial production projects, then points out the potential manufacturing prospects. After comparing the symbolic floating bodies, it is implied that our current independent construction technology can satisfy the requirements derived from NGH trial production water depth in South China Sea. Actually, some indicators may even exceed the critical demands. Since these symbolic floating bodies are generally high cost with expensive daily rental, the existing cases would be like using anti-aircraft guns to fight mosquitoes. Therefore, higher technology matching should be considered preferentially for cost control. The localization multi-phase separation equipment is relative laggard, while the global higher technical level is also unable to meet the demand of deep water NGH commercial production. The related technology and equipment are in urgent need of development. ROV has the basic ability of offshore NGH survey and underwater operation, but coming to the more complex tasks, it should be gradually improved for better job. The advanced deep water seabed mining vehicle can preliminarily perform well for solid fluidization, but more targeted design and special improvement should be made in combination with the NGH characteristics. Increasing marine NGH development efficiency...
and maintaining safety on the basis of meeting the requirements of trial production and environmental protection are the key points to technology research and development for ocean engineering equipment in the next stage.

**Keywords:** Ocean engineering equipment · Chinese NGH resource · Marine trial production · Floating body · Underwater devices · Application prospects

### 1 Introduction

The global energy structure is shifting with the progress of technology, and the proportion of marine oil and gas in the total fossil energy consumption is increasing year by year. Besides the petroleum and shallow gas, natural gas hydrate is also one of these marine fuel resources, capturing large amounts of flammable gas in solid cages under high pressure and low temperature [1, 2].

Because of the characteristics such as huge reserve, wide distribution and high energy density, natural gas hydrate is gradually regarded as a new potential alternative energy resource with a bright future. According to the phase equilibrium conditions, it is believed that more than 30% surface of land and 70% surface of ocean can satisfy hydrate formation requirements. The existing geological survey results indicate that there are abundant NGH resources buried in both the sediments of the permafrost (like Qilian Mountain, Tibet Plateau and Great Khingan, etc.) and ocean (like South China Sea) of China, leading to the great natural advantages for the mineral industrialization. Extracting flammable gas from the hydrate reserved in the sediments is beneficial to improve the traditional energy structure and enhance the national energy strategic security.

The marine NGH trial production projects started much later but developed rapidly, especially in the recent years. On the one hand, it is said that the total amount of hydrate deposits in continental slopes under sea water is much larger than that reserved in permafrost. On the other hand, although there are only 5 marine NGH trial production cases up to now, the production efficiencies of them are generally better with higher maximum daily production rates. Therefore, the sea area will be the main battlefield for natural gas hydrate development in the future.

To extract the flammable gas out of the solid cages buried in the sedimentary layers, a series of development methods, such as depressurization, thermal stimulation, chemical inhibitor injection, solid fluidization and CO₂ replacement, are gradually proposed based on the NGH phase transition characteristics and sedimentary properties. All these methods have their own unique merits and limitations. In which, depressurization is found to be the most widely applied in the previous trial production cases due to its low cost, little demand and convenient operation, while solid fluidization is regarded as the most suitable method for the marine loose weak-cemented sedimentary layers.

The NGH commercial production threshold is still hard to reach so far depending on the current technology and development modes. High investment cost, low gas production capacity and numerous engineering accident risks are undoubtedly important reasons, and directly or indirectly determined by the ocean engineering equipment providing supports for nearly all the operations. This research summarizes and analyzes the application status of special ocean engineering equipment, such as floating body
and underwater devices, applied in NGH trial-production projects, then points out the potential development and manufacturing prospects.

2 Floating Body

2.1 Applications in Existed Marine NGH Trial Production Cases

Common floating bodies used in offshore oil and gas exploration and development include drilling vessels and platforms. Presently, Japan and China are the only two countries around the world that have carried out the few marine NGH trial production projects, in which drilling vessels named ‘Chikyu’, and ‘HYSY708’, as well as drilling platforms named ‘Blue Whale I’ and ‘Blue Whale II’ are the symbolic floating bodies picked up respectively [3–5].

‘Chikyu’ is the first ocean drilling vessel all over the world that uses riser for drilling, sponsored by Japanese government, owned by JAMSTEC and operated by CDEX. The vessel is 210 m long, 38 m wide and 16.2 m high with a capacity of 200 people and a full load displacement of 57500 tons. Equipped with six full rotary thrusters of 4200 kW, one bow thruster of 2550 kW, six main diesel generators of 5000 kW and two auxiliary generators of 2500 kW, the drilling vessel has a maximum range of 20000 nautical miles, a maximum speed of 12 knots, and the capable to position at 4.5 m wave height, 23 m/s wind speed and 1.5 throttle speed. In addition, with the assistance of a derrick of 70 m high and a hook load of 1250 tons, Chikyu can adopt 10000 m pipes for drilling, and its maximum working water depth is 2500 m, which can be further extended to 4000 m.

A main function of Chikyu is to sample the seabed soil. The laboratory onboard can conduct timely petrological, paleontological, geophysical and geochemical analyses of extracted core samples. The core samples can be kept at low temperature in the refrigerated store to transported back to land for further study. Considering these characteristics, Chikyu was chosen for application in the first marine NGH trial production project in 2013. The gas hydrate buried 1000 m water depth and 300 m below mudline was obtained by depressurization.

HYSY708 is the first survey vessel with a water depth of 3000 m all over the world that integrates multi functions such as drilling, offshore working and exploration, owned by CNOOC and operated by COSL. It is 105 m long, 23.4 m wide and 9.6 m high with a full load displacement of 11600 tons. As the survey vessel with the strongest comprehensive operation ability of the same type, HYSY708 can ensure safe navigation under Grade 9 sea conditions, storm and even hurricane. Under the design draft conditions, its navigational speed is up to 14.5 nautical miles, and lifting weight is up to 150 tons. Considering its maximum working water depth of 3000 m, maximum drilling depth of 600 m below mudline, maximum sampling length of 23.5 m under constant pressure and temperature, HYSY708 was chosen to extract hydrate resources in South China Sea by solid fluidization in 2017.

Blue Whale I and Blue Whale II are two similar drilling platforms of the same series, designed by CIMC RAFFLES and verified by DNV, specially constructed for marine NGH trial production projects in 2017 and 2020. Currently, they are the world’s deepest semi-submersible drilling platforms, which can be used in 95% of the world’s deepwater operations. They are 117 m long, 92.7 m wide, 118 m high, and weighs
42000 tons. Equipped with hydraulic twin rigs, closed loop power system and DP3 dynamic positioning system, the operation efficiency can be improved by 30%, the fuel consumption can be reduced by 10% and the offset accuracy can be controlled within 0.5 m even under the attack of hurricane and current. Their working water depth is up to 3658 m and drilling depth is up to 15250 m.

2.2 Technology and Development Directions

The exploration results show that most of hydrate resources in South China Sea are reserved in the shallow layers under deep water, such as the loose weakly-cemented sediments with a water depth of 800–1500 m and buried depth within 500 m. Compared with common near-shore exploration and development, deep water operations need to face more frequent and violent storms, waves and currents, as well as stronger impact and corrosion effects. In addition, the increase of water depth may enhance the bending moment strength, the influence of complex internal wave flow and the effect of offset oscillation on the subsea products such as subsea pipelines. Therefore, it also puts forward higher requirements for the size, weight, positioning accuracy and stability of the floating bodies.

![Fig. 1. Analysis of the representative floating bodies evaluated by water depth](image)

Taking the water depth as the key reference criteria, the representative floating bodies including the ones mentioned above are evaluated through comparative analysis, as shown in Fig. 1. The results show that all of them, including Deep Sea No.1 (the world’s
most advanced deep water semisubmersible production and storage platform), are competent for the demands derived from water depth of NGH drilling and production in South China Sea, indicating that the existing technology of deep water floating body technology can fully cope with the water depth challenges faced by NGH development projects in South China Sea. Some indicators may even exceed the critical demands. The satisfaction of the technical indicator (water depth here) does not mean large-scale promotion for industrial application. More factors should be taken into consideration, for example, the total input costs. It is said that each floating body applied in marine NGH trial production cases costs hundreds of millions or even billions of dollars for construction, and the corresponding daily rental and employee fees are also expensive, resulting these cases would be like using anti-aircraft guns to fight mosquitoes. What’s more, in order to alter the short-term trial production into long-term commercial production, suitable storage floating body should be selected based on these drilling floating bodies. In the follow-on process of design and construction, it is advised that higher technology matching NGH reservoir in South China Sea should be considered preferentially for cost control, and the floating body should be tailored for a better utilization.

3 Underwater Devices

Besides the large size ocean engineering equipment such as floating body, special process technology, like multi-phase separation, and certain under water devices, like remote operated vehicle and seabed mining vehicle, are also needed during marine NGH trial production. In which, the localization multi-phase separation equipment is relative laggard, while the global higher technical level is also unable to meet the demand of deep water NGH commercial production. So the related technology and equipment are in urgent need of improvement.

3.1 Remote Operated Vehicle

Remote operated vehicle (ROV) is a special underwater device used for monitoring subsea variations and executing operations. It can replace divers in hazardous, polluted and dim environments, breaking the original water depth limits and avoiding casualties. In marine NGH trial production, ROV can be applied for geology survey, core sampling and etc. [6].

‘Haima’ is one of the most advanced ROV which is independent-made by China. Certain key software and hardware technologies, including body structure, propeller, navigation system, heave compensator and multi-function manipulator, have been improved during the process of localization, as shown in Fig. 2. In 2014, several tests were carried out at the bottom of central basin in South China Sea, verifying that ‘Haima’ has the capability of underwater cable distribution, sediment sampling, subsea seismograph placement and other tasks. Since its maximum diving depth is 4502 m, much deeper than the marine gas hydrate buried positions, ‘Haima’ has been already used for NGH survey in South China Sea. Although the basic operations are already available, the ability of ROV to obtain more useful information and automate complex operations needs to be further enhanced with exploitation technology progress.
3.2 Seabed Mining Vehicle

Seabed mining vehicle is a special underwater device used for collecting subsea mineral resources in the shallow layers. Guided by ROV, it can migrate to target areas and break mineral into small blocks and pieces. As marine NGH partially distributed on the seabed surface or in the shallow layers, this underwater device can be adopted as a critical component for solid fluidization. Up to now, the domestic advanced deep water seabed mining vehicle can autonomous collect the subsea minerals with a maximum diving depth of 1305 m, while the world’s advanced deep water seabed mining vehicles have more types and their diving depth is up to 1600 m or more, as shown in Fig. 3 [7].

After comparison, it can be seen that the existing deep-sea mining vehicles are basically capable of assisting and participating in NGH development in the South China Sea. However, targeted design and special improvement on seabed mining vehicle still need to be made in combination with the NGH characteristics, as well as the detailed process of solid fluidization.
4 Conclusions

(1) Chinese independent construction ability for floating body can satisfy the requirements of NGH trial production water depth in South China Sea now. In the follow-up works, higher technology matching should be considered preferentially for cost control.

(2) ROV and seabed mining vehicle has the primary ability of deepwater NGH survey, underwater operation and solid fluidization on seabed surface, but they should be further improved for better work.

(3) Increasing marine NGH development efficiency and ensuring safety are the key points to technology research and development for related marine devices.

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References

Analysis of Influence of Hydrate Decomposition on Underwater Wellhead Stability

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Abstract. During deep-water drilling, it is easy to encounter hydrate interlayers. Due to engineering disturbances, hydrates may decompose and cause the formation strength to decrease, which will cause the formation settlement and the wellhead instability. In this paper, based on the ABAQUS finite element platform, a wellhead stability calculation model for deep-water drilling encounter hydrate formations is established, and the influence of hydrate decomposition and drilling time on wellhead stability is analyzed. The research results show that the circulation of high-temperature drilling fluid in the annulus will change the formation temperature distribution. The top formation will heat slowly due to its low temperature and the cooling effect of seawater. The middle formation is greatly affected by the drilling fluid, and the lower undrilled stratum remains unchanged because it has not been disturbed by the engineering. The increase in formation temperature will cause the decomposition of hydrates, leading to a decrease in the elastic properties and strength of the near-well formation. The formation with weakened mechanical properties will produce secondary compression and consolidation, and secondary stress concentration will be formed in the hydrate saturation transition zone. This is the essential reason for the effect of hydrate decomposition on the vertical stability of the formation and wellhead. As the drilling time increases, the hydrate decomposition range increases, the bearing capacity of the formation in a larger area decreases, and the risk of underwater wellhead instability increases. However, since the hydrate decomposition area is located below the underwater wellhead at the initial moment, it will have a more serious impact on the stability of the underwater wellhead. The research in the thesis can provide a theoretical basis for the maintenance of wellhead stability in deep-water drilling.

Keywords: Deep-water drilling · Wellhead subsidence · Natural gas hydrate

1 Introduction

Natural gas hydrate is a clathrate crystal compound formed by methane molecules and water molecules under the conditions of low ambient temperature and high pore pressure. Natural gas hydrates are widely present in the shallow strata of the deep sea. During deep-water drilling, a large number of hydrate interlayers may be encountered [1]. Due
to engineering disturbances, the temperature field, pressure field and chemical field of
the hydrate formation will change, leading to the decomposition of hydrate [2]. As the
hydrate formation is usually shallow, the sediments are in a weakly consolidated state,
and the hydrate molecules will act as a framework in the pores of the soil [3]. The
decomposition of hydrate will cause the formation strength to decrease, and the soil
will be compressed due to secondary compaction, which will lead to the settlement of
the underwater wellhead, and even the instability of the underwater wellhead in severe
cases [4].

2 Numerical Model of Effect of Hydrate Decomposition
on Underwater Wellhead Stability

According to logging data from the South China Sea, natural gas hydrates are mainly
found in the formation at a depth of about 200 m from the mudline, with a thickness
of 25 m. Therefore, a two-dimensional axisymmetric deep-water drilling underwater
wellhead stability numerical model can be established as shown in Fig. 1. The whole
model can be divided into four parts, overlying strata, hydrate strata, underlying strata,
and casing. The whole model can be divided into four parts, overlying strata, hydrate
strata, underlying strata, and casing. The outer diameter of the strata is 200 m, of which
the thickness of the overlying strata is 195 m. The thickness of the hydrate layer is 25 m,
the initial saturation is 0.45, and a 2 m thick hydrate transition zone is set in the upper
and lower sections of the hydrate layer. The thickness of the underlying strata is 195 m.
The size of the surface conduit is 30″, the wall thickness is 1″, and the diameter of the
wellbore in hydrate formation is 26″. The casing only seals the overlying formation, that
is, there is no seepage effect between the drilling fluid and the overlying formation, but
only heat transfer. Gravity load, initial in-situ stress field, initial temperature field and
initial pore pressure field varying with depth are applied to the entire model. The initial
hydrate saturation field is applied to the hydrate layer. The upper boundary of the model
imposes pore pressure boundary equal to the hydrostatic column pressure of seawater
and temperature boundary equal to the temperature of the seabed mudline. The lower
boundary of the model imposes fixed pore pressure boundary, temperature boundary and
Y-direction displacement constraints. X-direction displacement constraint is imposed on
the right boundary of the model; A fixed load is applied to the top of the casing, which is
equal to the floating weight of the underwater wellhead, blowout preventer (BOP) and
riser. The borehole section of the hydrate layer imposes drilling fluid column pressure
load, pore pressure boundary and temperature boundary. The calculation of the entire
model is divided into two analysis steps. Step 1 is the in-situ stress balance, and the step
2 is the analysis of the stability of the underwater wellhead during the drilling process.
The selected drilling method is balance drilling with high-temperature drilling fluid. The
parameters used in model calculation are shown in Table 1.
3 Evolution of Underwater Wellhead Stability with Drilling Time

Figure 2 shows the formation temperature distribution of different drilling fluid soaking time. It can be seen that the circulation of high-temperature drilling fluid in the annulus will seriously change the temperature distribution of the formation, and the area near borehole will be heated due to the soaking of the drilling fluid. The top formation will heat slowly due to its low temperature and the cooling effect of seawater. The middle formation is greatly affected by the drilling fluid, and the lower undrilled stratum remains unchanged because it has not been disturbed by the engineering. For example, after the borehole is drilled for 6 h, the borehole temperature at 0.65 m formation depth is 24.8 °C, the hydrate layer borehole temperature is 30 °C, and the bottom formation remains the same as the initial temperature of 24.6 °C. At the same time, it can be seen that as the drilling time increases, the formation heated by the drilling fluid gradually increases. For example, after 6 h of drilling, the range of 220 m depth affected by drilling fluid temperature is 0.52 m, and after 24 h, this range reaches 1.04764 m. Due to the heating effect of the drilling fluid, the hydrate in the pores gradually decomposes. With the increase of the influence range of the drilling fluid temperature, the hydrate decomposition range gradually increases, as shown in Fig. 3. After 6 h of drilling, the decomposition front in the middle of the hydrate layer was 0.2264 m, or 0.68 times the radius of the borehole; after 12 h of drilling, the hydrate decomposition front advanced to 0.3067 m, which was 0.93 times the radius of the borehole.
The decomposition of hydrate will cause the formation elastic properties and strength to decrease, and the formation will be consolidated by secondary compression. Figure 4 shows the vertical deformation distribution of the hydrate layer at different drilling times. It can be seen that in hydrate decomposition area, the upper strata is deformed downwards, and the lower strata are deformed upwards. The deformation of the upper strata is higher than that of the lower strata, such as after drilling for 12 h, the deformation of the upper strata is 0.03816 m, and the compression of the lower strata is 0.01798 m. The former is 2.12 times that of the latter. This is because the upper strata not only bears the in-situ stress, but also bears the load caused by the settlement of the casing and the underwater wellhead.

Figure 5 and Fig. 6 show the mises stress distribution on the top and bottom layers of the hydrate. The formation around the borehole wall has a decrease in stress due to weakening of elastic parameters and plastic deformation. It can be seen that the upper stratum has a larger stress drop area than the lower stratum, and the maximum mises stress value of the stratum at the same time is higher, such as after 12 h of drilling, the maximum Mises stress in the upper strata is 9.67 MPa, and the lower strata is 7.13 MPa. As the drilling time increases, the location of the maximum Mise stress gradually develops toward the far well. The softening and compression of the hydrate formation caused by the decomposition of hydrate will aggravate the settlement of the underwater wellhead. Figure 7 shows the distribution cloud diagram of underwater wellhead settlement under different drilling time. It can be seen that the initial stage of hydrate decomposition has a greater impact on the underwater wellhead settlement. Such as at initial 6 h, the underwater wellhead has a settlement of 0.1365 m, while the subsea wellhead subsidence increased by 0.028 m from 6 h to 12 h, and the subsidence only increased by 0.0149 m from 12 h to 24 h. This is because, on the one hand, with the increase of drilling time, the development of the influence range of drilling fluid temperature and the range of hydrate decomposition gradually decreases. On the other hand, the initial decomposed hydrate formation is located under the casing, it has a more direct impact on the settlement of the underwater wellhead.

Therefore, when deep-water drilling encounters a hydrate layer, the decomposition of the hydrate will cause the softening of the hydrate layer and aggravate the settlement of the underwater wellhead. In the early stage of drilling fluid immersion, the hydrate decomposition front advances faster, which has a greater impact on the settlement of the underwater wellhead. As the immersion time increases, the advancing speed of the hydrate decomposition front decreases, and the subsidence speed of the underwater wellhead gradually decreases.
Fig. 2. Formation temperature vs. distance to the borehole wall, in cases of varied soaking time in drilling fluids.

Fig. 3. Hydrate saturation vs. soaking time in drilling fluids.
Fig. 4. Lateral deformation of the hydrate-bearing sediment vs. soaking time in drilling fluids (magnified by 30 times)

Fig. 5. Mises stress distribution of the upper formation

Fig. 6. Mises stress distribution of the lower formation