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Design and feasibility analysis of a new completion monitoring technical scheme for natural gas hydrate production tests

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ABSTRACT

As a prerequisite and a guarantee for safe and efficient natural gas hydrates (NGHs) exploitation, it is imperative to effectively determine the mechanical properties of NGHs reservoirs and clarify the law of the change in the mechanical properties with the dissociation of NGHs during NGHs production tests by depressurization. Based on the development of Japan's two offshore NGHs production tests in vertical wells, this study innovatively proposed a new subsea communication technology—accurate directional connection using a wet-mate connector. This helps to overcome the technical barrier to the communication between the upper and lower completion of offshore wells. Using this new communication technology, this study explored and designed a mechanical monitoring scheme for lower completion (sand screens). This scheme can be used to monitor the tensile stress and radial compressive stress of sand screens caused by NGHs reservoirs in real time, thus promoting the technical development for the rapid assessment and real-time feedback of the *in-situ* mechanical response of NGHs reservoirs during offshore NGHs production tests by depressurization.

1. Introduction

NGHs are considered the most potential substitutes for clean energy in the oil and gas fields due to their wide distribution, small burial depth, cleanness, non-pollution, and huge reserves. Gas hydrate exploration studies have increased substantially since last decade (Merey Ş and Longinos SN, 2019). Japan conducted the world's first offshore NGHs production test in the Nankai Trough in 2013 and then carried out its second NGHs production test from April to June in 2017 (Li SD et al., 2019; Zhang W et al., 2017). China conducted its first and second offshore NGHs production tests in the Shenhu Area of the South China Sea from May to July in 2017 (Li JF et al., 2018) and from October 2019 to April 2020 (Ye JL et al., 2020), respectively.

Depressurization is considered the most cost-effective and efficient technology for gas production from offshore NGHs sediments (Wu NY et al., 2020; Zhang XH et al., 2019; Shaibu R et al., 2021; Qin XW et al., 2022). However, offshore NGHs production by depressurization inevitably poses potential engineering geological risks such as the instability of strata (Wan YZ et al., 2018) and large-scale sand production (Li YL et al., 2017) and may also lead to the depletion of both the materials and the energy in strata (Mok J et al., 2020; Dufour T et al., 2019). There is an urgent need for solving these adverse effects. Studies of NGHs industrialization have always focused on the R&D of technologies for long-term stable gas production, and the prerequisite for safe and efficient NGHs exploitation is to effectively determine the mechanical properties of NGHs deposits and clarify the law of the change in the mechanical properties with the dissociation of NGHs (Moridis GJ et al., 2007, 2010; Xin X et al., 2020; Li WL et al., 2019; Lijith KP et al., 2019; Ning FL, 2005; Yu XH et al., 2019; Wei CF et al., 2020).

Owing to technical constraints, the *in-situ* stress response of NGHs reservoirs around production wells has not been

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monitored yet during offshore NGHs production tests at home or abroad. It is therefore very important to develop *in-situ* monitoring technologies to directly monitor the creep and the subsidence and compaction mechanisms of reservoirs during NGHs production tests by depressurization. This study aims to accurately assess the mechanical response of reservoirs during offshore NGHs production tests by depressurization in order to achieve accurate depressurization and long-term stable gas production during production tests. To this end, this study investigated the completion characteristics of vertical production wells used in Japan's two NGHs production tests. Afterward, it innovatively proposed a new technical method to overcome the communication barrier between the upper and lower completion based on the original monitoring systems comprising temperature and pressure gauges and distributed optical fibers. Using the new communication method, this study designed a monitoring scheme for the tensile stress and radial compressive stress caused by subsidence and compaction of NGHs reservoirs during depressurization through the lower completion (sand screens) and carried out a feasibility analysis of the scheme. In this manner, NGHs production tests by depressurization can be combined with engineering geology, thus promoting the technical development of the rapid assessment and real-time feedback of engineering geological parameters involved in the mechanical response of NGHs reservoirs during NGHs production tests by depressurization (Wei CF et al., 2020).

2. Current status of the monitoring in offshore NGHs production tests conducted by Japan

Engineering geological monitoring during NGHs production tests, except for the atmospheric environment monitoring for methane leakage and ocean current monitoring, are primarily carried out at monitoring and production wells and on the seabed (Fig. 1). To explore the commercialization of NGHs development by depressurization, various techniques for monitoring reservoir temperature and pressure, the pore pressure parameters of submarine sediments, the leakage of submarine methane, and the stability of sub-seabed strata (subsidence and landslides) are combined to comprehensively assess the geomechanical response of reservoirs during NGHs production tests by depressurization and reservoir depressurization (Li JF et al., 2018; Ye JL et al., 2020).

2.1. Monitoring method in a monitoring well

As shown in Fig. 1, there is a certain distance between the

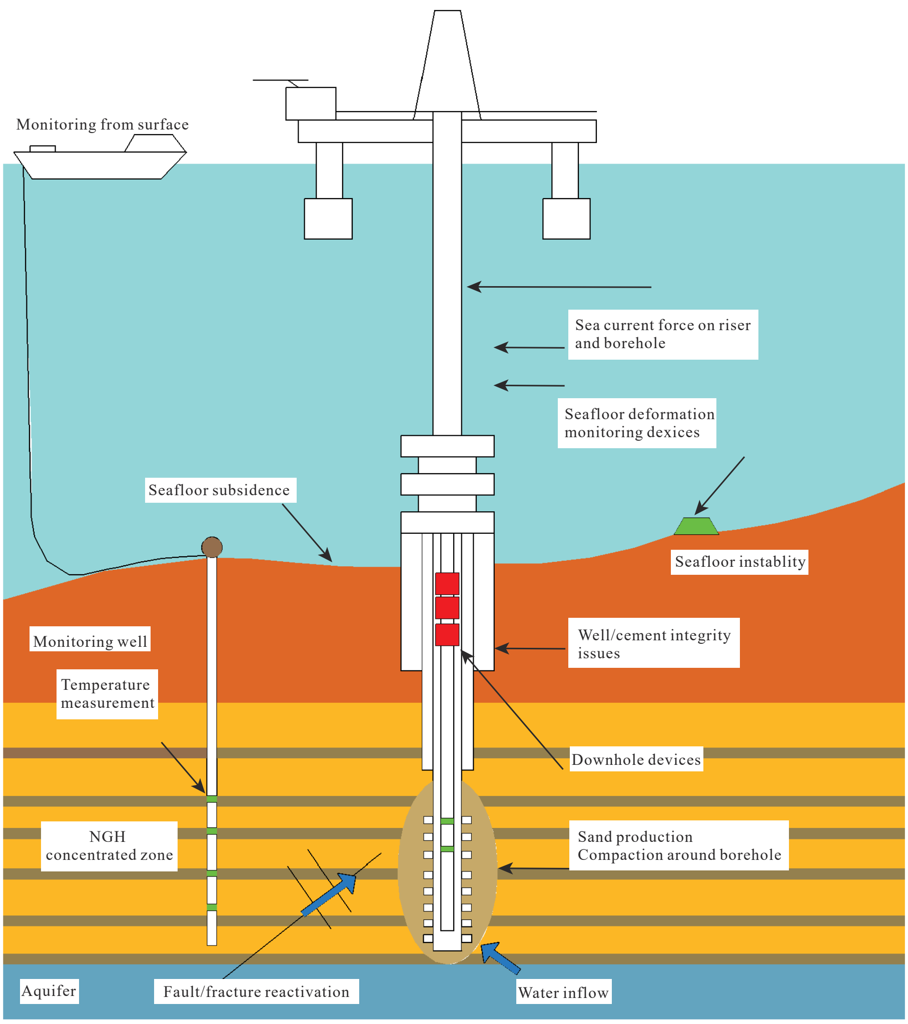

Fig. 1. Possible geomechanical issues induced by NGHs dissociation (modified from MH21，2019).

monitoring well and the production well during an NGHs production test. The temperature and pressure monitoring devices are arranged in a monitoring well to assess the propagation speeds and changing amplitudes of temperature and pressure induced by NGHs dissociation during NGHs production by depressurization in production wells. During the second NGHs production test conducted by Japan in 2017, two monitoring wells were used to monitor the production well. They were 20 m and 47 m from the production well, and the following cables were deployed below the mudline in the monitoring wells (MH21, 2019; Matsuzawa M et al., 2014):

(i) Distributed temperature sensing (DTS) cable [0.433″ (11 mm) x 0.433″ (11 mm)]: Polypropylene encapsulated optical fiber cables for the DTS;

(ii) Electrical cable (TEC line) [0.433″ (11mm) x 0.433″ (11 mm)]: Polypropylene encapsulated electrical cable for pressure and temperature gauges;

(iii) Resistance temperature detector (RTD) electrical cables.

2.2. Completion and monitoring technology of production wells

Fig. 2 shows the structures of the drilling and completion of production wells used in Japan's two offshore NGHs production tests.

The production well used in the first production test is shown in Fig. 2. According to this figure, 9-5/8″ casing was lowered above the top of NGHs reservoirs for well cementing and packing. Afterward, NGHs reservoirs were drilled. The sand screens for the lower completion were lowered into NGHs reservoirs via the 9-5/8″ casing. After gravel packing for well completion and sand control, the testing strings for upper completion (including a subsea test tree, completion strings, and the temperature and pressure monitoring strings in the wellbore in the reservoir section from top to bottom) were lowered in place. Moreover, the cable for the electric submersible pumps, electrical cable for pressure and temperature gauges, and the hydraulic lines for chemical injection were fixed to the testing strings of the upper completion and lowered into the production well.

During the first production test conducted by Japan, the bottom string of the testing strings for upper completion, to which DTS cable, hydraulic line for chemical injection, and electrical cable for pressure and temperature gauges were tied using clamps, was lowered into the base pipe with an inner diameter of 4.894″ (124.3 mm) (the wellbore in the reservoir section) of gravel-packed sand screens. Moreover, the changes in temperature and pressure in the base pipe were monitored to indirectly analyze the changing mechanisms of temperature and pressure of pores connected to the NGHs reservoirs in the wellbore. Since the monitoring instruments were not in direct contact with the reservoir sediments, the mechanical response of reservoirs could not be monitored yet.

Cables deployed below the mudline included:

(i) 4AWG flat electrical cables [1.693″ (43 mm) × 0.669″ (17 mm)] and round electrical cables (outer diameter: 30 mm) for the electric submersible pump;

(ii) DTS cable [0.433″ (11 mm) × 0.433″ (11 mm)]: Polypropylene encapsulated optical fiber cables for the DTS;

(iii) Electrical cable (TEC line) [0.433″ (11 mm)× 0.433″ (11 mm)]: Polypropylene encapsulated electrical cable for pressure and temperature gauges;

(iv) Hydraulic chemical injection line [0.512″ (13 mm) × 0.512″ (13 mm)]: Polypropylene encapsulated hydraulic line for chemical injection.

Japan carried out its second production test to further explore the commercial NGHs development mode. The open water workover system (OWS) was used at the wellheads in the second production test to replace the traditional blow out

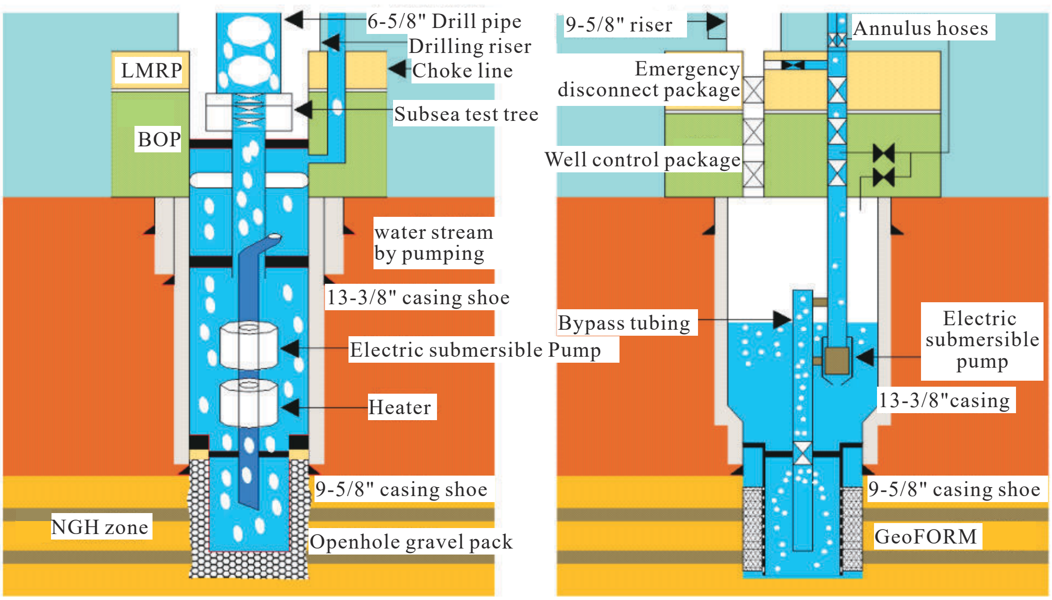

Fig. 2. The downhole system for the first test (left) and second test (right) in Japan (modified from MH21, 2019; Matsuzawa M et al., 2014; Zhang W et al., 2017).

preventer (BOP) system and the subsea test tree used in the first production test. As a result, the technical requirements for wellhead stability were reduced and the rapid switching between wells AT1-P3 and AT1-P2 was achieved. During the drilling operation of the production wells, the 13-3/8″ casing + crossover + 9-5/8″ casing nipple were directly lowered to a distance above the top of NGHs reservoirs. After cementing and packing the overlying strata, NGHs reservoirs were drilled. For the lower completion, GeoFORM sand screens were embedded into NGHs reservoirs for sand control viathe 9-5/8″ casing, and the sand screens' packer was set onto the 9-5/8″ casing nipple. In terms of upper completion, the artificial lift system 's completion strings used a common Y-tool structure, and the electric submersible pump was placed into the 13-3/8 ″ casing section, which improved the gravity separation efficiency over the 9-5/8 ″ casing. The reservoir temperature and pressure monitoring in the lower completion strings was roughly the same as that adopted in the first production test.

2.3. Engineering geological monitoring in the two NGHs production tests conducted by Japan

Table 1 shows the basic conditions of the two production tests conducted by Japan.

During the first offshore NGHs production test in the Nankai Trough in 2013, seabed deformation was measured for the first time. Specifically, centimeter-level seabed subsidence was indirectly detected at the top of production wells using seabed deformation instruments, which indirectly proved that reservoirs would subside to a certain extent during NGHs production tests. Moreover, a large amount of sand was produced in Well AT1-P after six days of NGHs production by depressurization. During the second NGHs production test conducted by Japan in 2017, sand production also occurred in production well AT1-P3, and the production test in this well was terminated in advance (MH21, 2019).

Extensive laboratory simulation studies have been carried out on the mechanisms of sand production during NGHs production tests, achieving great progress. However, the reasons for sand production have not yet been completely determined due to the lack of on-site monitoring data on the mechanical response of sand screens (Ning FL et al., 2020; Lu JS et al., 2020; Dong CY et al., 2019; Abbas AK et al., 2019). To investigate the reasons for the centimeter-level subsidence of the seabed surface and a large amount of sand production detected in well AT1-P during the first production test, Japanese researchers (Yoneda J et al., 2018) developed a multiphase coupling simulator named coupled thermo-hydro-mechanical analysis (COTHMA) using the finite element method to predict the hydrate dissociation-induced stress change and deformation around the production well during the production test. The predicted results showed that the seabed would subside by approximately 30 cm after one year of continuous production. The predicated results also revealed that the casing shoe would be vertically stretched downward subject to reservoir compaction. As a result, tensile stress would be generated inside and around the casing shoe, and this may be the reason for the large-area damage to gravel packing in the process of well completion.

Massive studies have been carried out on the relationship between NGHs production tests by depressurization and the pressure response of reservoirs through laboratory and numerical simulations (Wei CF et al., 2020; Li Y et al., 2021). However, it is difficult to obtain actual mechanical responses of reservoirs through engineering geological simulation and assessment. Most especially, the NGHs simulation cannot present the maximum constraints of engineering geological risks such as reservoir subsidence, sand production, instability, and even landslides during the actual NGHs production tests (Wu NY et al., 2020).

3. Design of a new technical scheme for lower completion monitoring

3.1. Connection and communication using a subsea wet-mate connector

A subsea test tree is a key device for risk control during

Table 1. Basic conditions and results of two offshore production tests conducted by Japan (modified from MH21, 2019; Matsuzawa M et al., 2014).

Statistics of two production tests	The first production test in 2013	The second production test in 2017	
	Well No. 1 (AT1-P)	Well No. 1 (AT1-P3)	Well No. 2 (AT1-P2)
Duration	Six days and 10 hours	12 days, 5 hours, and 20 minutes	24 days, 4 hours, and 5 minutes
Decreased amplitude of pressure	13.5–4.5 MPa	13–5.15 MPa	13.0–8.0 MPa
Production interval	39 m	41 m	41 m
Sand control method	Gravel packing	Wellhead pre-expansion using the GeoFORM system	Downhole expansion using the GeoFORM system
Drainage method	Choke line/kill line	Two 1" ID hoses	Two 1" ID hoses
Total gas production	119000 m^3	40849.9 m^3	222587.1 m^3
Daily gas production	20000 m^3/d	3000–4000 m^3/d	10000 m^3/d
Total water production	1245 m^3	922.5 m^3	8246.9 m^3
Daily water production	200 m^3/d	80 m^3/d	More than 300-500 m^3/d at the later stage
Major events	30 m^3 of sand were produced after 5.5 days of production test; centimeter-level seabed subsidence was detected	Gas production was lower than predicated and simulated results; intermittent sand production occurred	A large amount of water more than predicted results was produced, and failures of the water train occurred

tests in deep waters. It can quickly disconnect the testing strings and pack the high-pressure oil and gas in the downhole strings under special ocean conditions, thus ensuring the safety of test instruments and personnel and avoiding marine pollution (Liu QY et al., 2013).

As shown in Fig. 2, a subsea test tree was used during the first NGHs production test conducted by Japan. Specifically, a subsea testing string was placed between the lower riser package (LMRP) and the BOP. It was used to provide emergency disconnection and safety protection by cooperating with the LMRP and BOP and to perform re-connection after an emergency to restore the NGHs production test. For example, an onshore emergency disconnection and re-connection trial test of a subsea test tree is shown in Fig. 3. In this test, both ends of a wet-mate connector were connected to 1/4 ″ thermobarometer communication cable installed on the upper and lower outer shrouds of the subsea test tree (as shown in Fig. 4), meeting the API Specification 6A. As a mature technology in the world, wet-mate technology has been widely applied in the deep-sea underwater electrical wet-mate field, especially in the underwater wet-mate field of deep-sea remotely operated vehicles (ROVs).

3.2. Coupling positioning technology of directional instruments for directional drilling

The directional drilling method is designed to control deviation and azimuth and determine the laws of their changes. Directional drilling can be technically achieved by controlling the deflection rate and toolface of directional tools. In the 1980s, coupling was used for the alignment between a directional instrument and a deflecting tool in the controlled directional drilling of traditional mines in China (Lu QP et al., 2020; Jiang TS et al., 1994). The most widely used coupling device consists of a guiding shoe and a directional sub with directional pins. This device can provide very reliable positioning effects, as shown in Fig. 5.

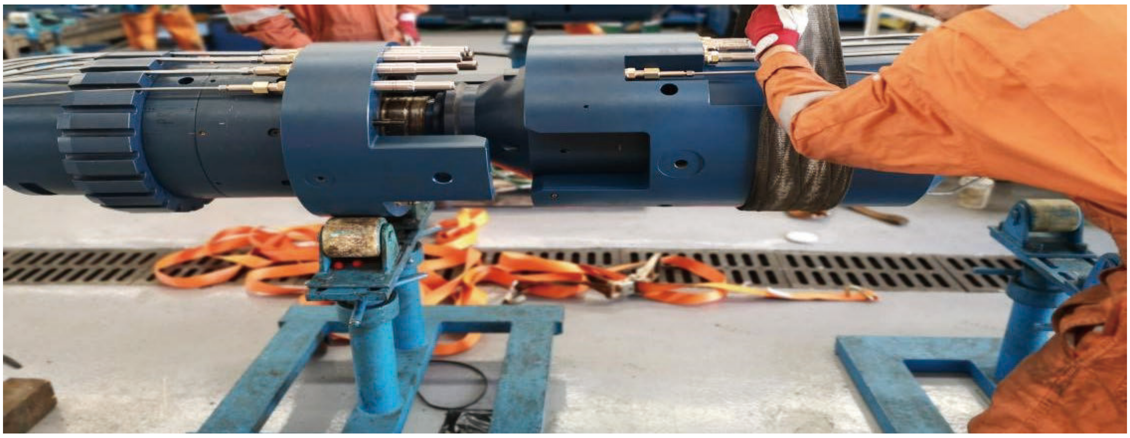

Fig. 3. Emergency disconnection and re-connection test of a subsea test tree onshore.

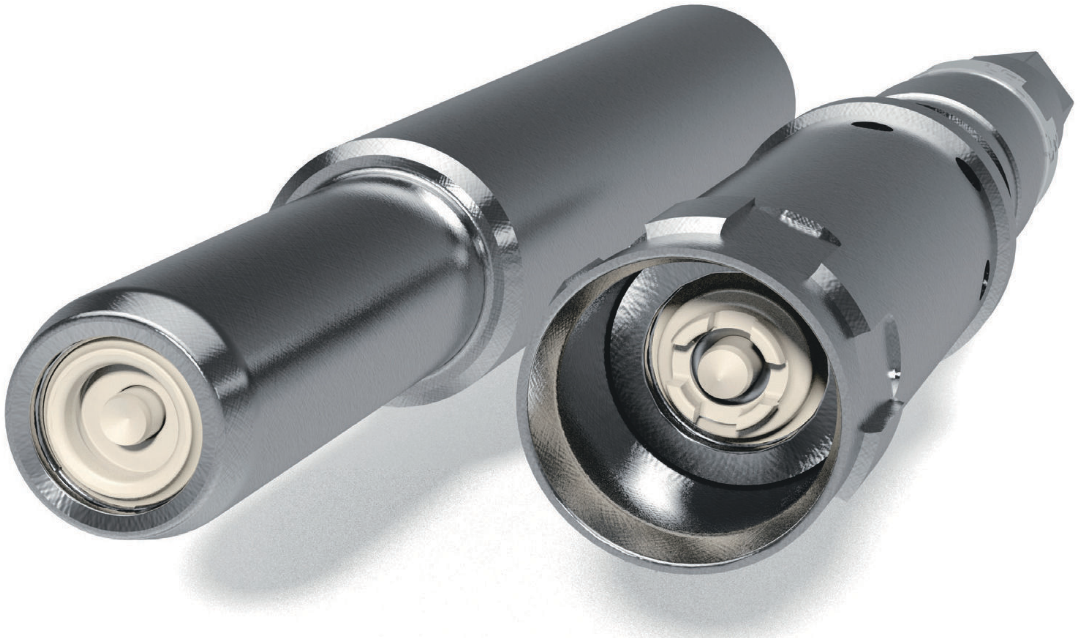

Fig. 4. A wet-mate connector used for the emergency disconnection and re-connection of subsea test trees.

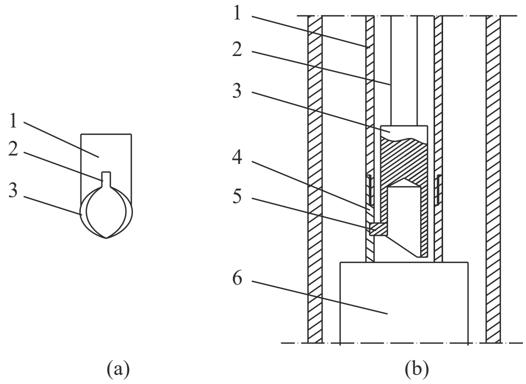

Fig. 5. Coupling device consisting of a guiding shoe and a directional sub. (a) Guiding shoe: 1–body of the guiding shoe; 2–directional groove; 3–spiral angular surface; (b) Coupling between the guiding shoe and the directional sub: 1–drill rod; 2–sensor of the directional instrument; 3–guiding shoe; 4–directional sub; 5–positioning pin; 6–deflecting tool.

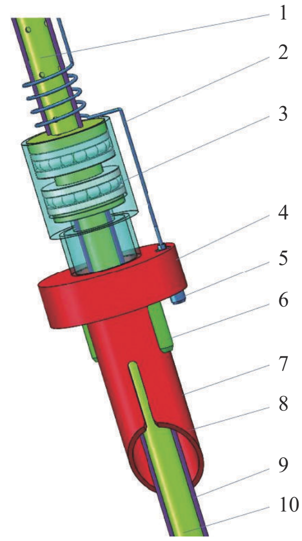

Fig. 6. Directional insertion-based communication device of upper completion. 1–oil tubing; 2–communication cable for upper completion; 3–single-acting mechanism; 4–centralizer; 5–wet-mate conductor; 6–protective front end of the wet-mate connector; 7–body of guiding shoe; 8–spiral angular surface; 9–DTS cable; 10–electrical cable for pressure and temperature gauges.

Specifically, when the sensor of the directional instrument is lowered to the directional sub, it is driven in place under the guidance of the spiral angular surface of the guiding shoe. When the spiral angular surface is in contact with the positioning pin, it slides on the positioning pin under the action of the sensor's gravity, until the directional groove of the guiding shoe slides into the positioning pin. Therefore, the positioning through the coupling between the guiding shoe and the directional sub is equivalent to that between the sensor of the directional instrument and the deflecting tool.

3.3. Design and implementation method of a new technical scheme for lower completion monitoring

Given the huge implementation costs of deep-sea NGHs production test projects, new technologies must be applied and implemented particularly reliably. The new technical scheme for lower completion monitoring was designed on the following principles:

(i) It should not affect the use of currently used monitoring technologies in NGHs production tests.

(ii) It should not affect the implementation of existing 7″GeoFORM sand screens.

(iii) Its failure should not affect the further implementation of NGHs production tests.

To break the barrier of communication between upper and lower completion, the new monitoring technology for the completion of production wells integrates the communication using a subsea wet-mate connector, insertion through coupling positioning, and a bearing-based single-acting mechanism (Fig. 6). Among them, the guiding shoe and the wet-mate connector (including its protective front end) are fixed firmly and connected. They are fixed onto the oil tubing through the bearing-based single-acting mechanism and can rotate around the oil tubing. The DTS cable and electrical cable for pressure and temperature gauges are designed to pass through the inner axle of the single-acting mechanism. The communication cable of the upper completion is wrapped around the oil tubing and connected to the wet-mate conductor. The body of the guiding shoe is allowed to rotate by a certain angle, which does not affect the safety of the connection between the cable and the wet-mate conductor.

Based on the drilling and completion of production wells in the NGHs production tests conducted by Japan, the overall design of the new monitoring scheme for the lower completion is as shown in Fig. 7. The accurate insertion through coupling positioning and the connection and communication using a wet-mate connector are achieved in four steps:

(i) The guiding shoe is lowered into the sand screens under the guidance of a centralizer.

(ii) The spiral angular surface of the guiding shoe contacts and slides along the directional pin at the top of the sand screens until the directional groove of the guiding shoe slides into the directional pin, thus achieving preliminary positioning.

(iii) The protective front end of the wet-mate connector is inserted into the positioning hole of the sand screens, thus achieving the second accurate positioning.

(iv) The wet-mate connector part of the upper completion is accurately inserted into the wet-mate connector part of the lower completion. In this way, the communication between the upper and lower completion is established.

According to the construction sequence, the lower completion strings are lowered to a certain depth in the wellbore and are then fixed through setting. Afterward, the upper completion strings are lowered into the well after being assembled in sequence and are hung at the subsea wellhead. To balance errors between construction and calculations and ensure the proper insertion and connection of the wet-mate conductor, an expansion joint is used in the upper completion strings. Moreover, in case the new monitoring scheme for the lower completion fails, the communication devices of the

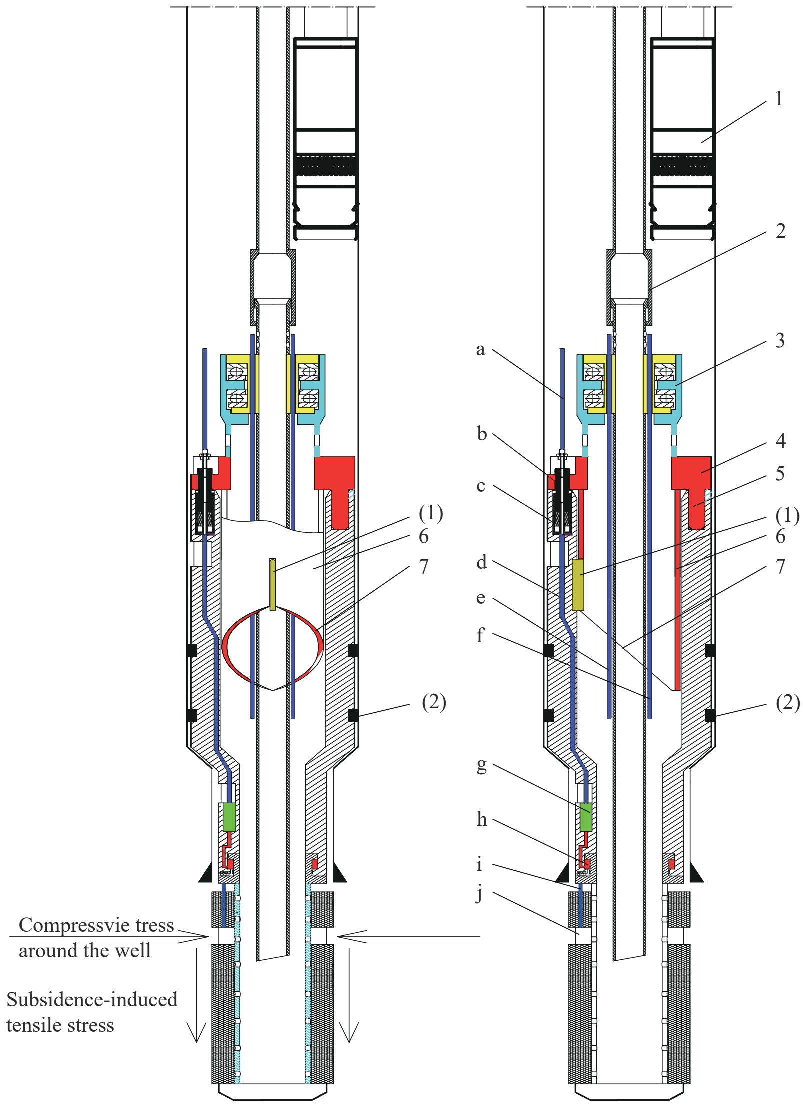

Fig. 7. Schematic diagram showing the design of the new monitoring technology for well completion of NGHs production tests. Upper completion: 1–Y-tool electric submersible pump for artificial lift; 2–expansion nipple; 3–single-acting mechanism; 4–centralizer; 5–protective front end of a wet-mate connector; 6–body of guiding shoe; 7–spiral angular surface. Lower completion: (1)–positioning pin of sand screen; (2)–packer of sand screens. Communication system and pressure testing mechanism of well completion: a–communication cable of upper completion; b–wet-mate connector (upper half); c–wet-mate connector (lower half); d–communication cable of lower completion; e–electrical cable for pressure and temperature gauges; f–DTS cable; g–piston-type pressure sensor; h–piston-type pressure measuring mechanism; i–communication cable for lower completion monitoring; j–radial pressure measuring mechanism.

upper completion that were directionally inserted through coupling hang on the top of the sand screens. Therefore, the failure of the new monitoring scheme will not affect the further implementation and later monitoring of the original production test, thus ensuring the construction safety.

The sand screens for the lower completion are in direct contact with NGHs reservoirs. Therefore, the stress response induced by reservoir depressurization can be directly measured by setting up corresponding measuring mechanisms. In the new monitoring scheme, the sand screens are equipped with a piston-type measuring mechanism. As a result, the longitudinal subsidence-induced tensile stress of NGHs reservoirs can be determined by monitoring the changes in the oil pressure of the measuring mechanism (no limit on the shapes of specific measuring mechanisms). Moreover, a measuring mechanism for radial pressure can be equipped on the sand screens to measure the transverse compressive stress around a well. In this way, the mechanical response of reservoirs can be monitored in real time during a production test by depressurization, thus meeting the urgent need for establishing the rapid assessment and real-time feedback mechanisms of engineering geological parameters during an NGHs production test by depressurization (Yu YJ et al., 2021a, 2021b).

4. Feasibility analysis of the construction of the new technical scheme for lower completion monitoring

The spatial requirements of the new technical scheme for lower completion monitoring are analyzed according to three main aspects:

(i) The spatial installation requirements regarding the radial dimension of the wet-mate connector;

(ii) The setting requirements of the setting mechanisms of packers and the tools used to lower sand screens;

(iii) The requirements for the sand screens ' base pipe inner diameter in the reservoir section (meeting the requirements for deploying temperature and pressure monitoring)

Assuming that API P110 casing is used in the construction according to the drilling and completion design of production wells in the second NGHs production test conducted by Japan, relevant dimensional parameters are as follows:

(i) 13-3/8" P110 casing, with a wall thickness of 12.19 mm and an inner diameter of 315.34 mm;

(ii) 9-5/8″ P110 casing, with a wall thickness of 11.05 mm and an inner diameter of 222.38 mm.

The new technical scheme was developed based on the design of the well bore structure adopted in the second NGHs production test conducted by Japan (Fig. 2 (right)). If the packer of the 7″ GeoFORM sand screens is set in 13-3/8″ casing (Fig. 7), whose inner diameter and annulus radius will be 92.96 mm and 46.48 mm greater than those of the 9-5/8″ casing, respectively, the top wall thickness of the packer of the sand screens will increase by 46.48 mm. The design experience of the wet-mate connector for a certain subsea test tree indicates that the mounting hole for the wet-mate connector has a size of 1.181″ (30.0 mm). Therefore, the above increased top wall thickness of the packer of the sand screens can meet the requirements for the installation size of the wet-mate conductor. Moreover, the requirements for the 1/4″ steel pipe housing the communication cable (armored rigid pipe with an outer diameter of 6.35 mm) to run through the packer of the sand screens can be met by the increased radial space of the 13-3/8″ casing compared with the 9-5/8″ casing. The technical requirements for the lowering, fishing, and setting of the sand screens can be met using products such as 7″ sand screens for lower completion, which have a top inner diameter of 194 mm and whose packer has an inner diameter of 168 mm. As shown in Fig. 7, the positioning pin of the sand screens has a design height of 13 mm, which can meet the technical requirements for the lowering and fishing of 7″ sand screens and the positioning and insertion of the wet-mate connector.

The software-based analysis results showed that no interference occurred in the directional insertion and communication between upper and lower completion under the above-mentioned size requirements (Fig. 8). Moreover, the method mentioned above had got a certificated patent in China (Fig. 9).

In sum, the radial space in the new technical scheme for lower completion monitoring can meet the designed installation requirements of the wet-mate conductor. Moreover, the new technical scheme poses no impact on further implementation of the original whole NGHs production test program and can provide real-time monitoring for the tensile stress and radial compressive stress of the sand screens produced by NGHs reservoirs during NGHs production tests by depressurization.

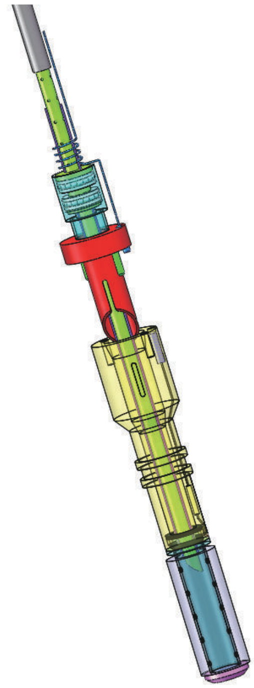

Fig. 8. 3D interference analysis of the communication connection between upper and lower completion through directional insertion.

5. Conclusions

An important step in achieving the future commercial exploitation of NGHs is to develop and improve monitoring technologies based on the direct contact with reservoirs to effectively determine the *in-situ* mechanical properties of NGHs reservoirs and clarify the law of the change in these mechanical properties with the dissociation of NGHs during NGHs production tests by depressurization. In this way, the coordination between accurate depressurization control and long-term stable production can be obtained. This study designed a new technical scheme for well completion monitoring in NGHs production tests, obtaining the following conclusions:

(i) The technical barrier to the communication between the upper and the lower completion strings can be broken using the innovative design that integrates the communication using a subsea wet-mate connector, insertion through coupling positioning, and a bearing-based single-acting mechanism.

(ii) The new monitoring technology for well completion was developed based on the well completion design adopted in the second hydrate production test conducted by Japan. The well completion communication between the upper and the lower completion strings can be practically applied by setting the original packer of the 7″ sand screens in 13-3/8″ casing. Therefore, new monitoring technology for well completion has a great application prospect.

(iii) Mechanical monitoring devices deployed in the lower


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发明专利证书

发明名称：一种建立上部完井管柱与下部完井管柱的通讯连接方法

发明人：于彦江;卢秋平;谢文卫;陆敬安;匡增桂;史浩贤;熊亮
康冬菊;谢莹峰

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授权公告日：2022年02月25日　授权公告号：CN 113187469 B

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第1页(共2页)

其他事项参见续页

Fig. 9. Certificated patent of the new communication connection between upper and lower completion.

completion (sand control screens) can directly monitor the mechanical response in the process of hydrate depressurization and can thus better serve the purpose of accurate depressurization in hydrate production tests.

Declaration of competing interest

The authors declare no conflicts of interest.

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References

Abbas AK, Ali H, Flori RE, Alhaideri H. 2019. Practical Approach for Sand-Production Prediction during Production. Geomechanics Symposium, 53rd U. S. Rock Mechanics

Dong CY, Yan QH, Li YL, Xu HZ, Zhou YG, Shang XS, Chen Q, Song Y. 2019. Numercial simulation of sand production based on a grain scale microcosmic model for natural gas hydrate reservior. Journal of China University of Petroleum (Edition of Natural Science), 43(06), 77–87. doi: 10.3969/j.issn.1673-5005.2019.06.009.

Dufour T, Hoang HM, Oignet J. 2019. Expenrimental and modelling study of energy efficiency of CO_2 hydrate slurry in a coil heat exchanger. Applied Energy (English Edition), 93(3), 492–505. doi: 10.1016/j.apenergy.2019.03.009.

Jiang TS, Zhou TF, Liu LS, Bi XK, Tang GQ. 1994. Controlled directional drilling technology. Beijing, Geological Publishing House, 98–150 (in Chinese with English abstract).

Li JF, Ye JL, Qin XW, Qiu HJ, Wu NY, Lu HL, Xie WW, Lu JA, Peng F, Xu ZQ. 2018. The first offshore natural gas hydrate production test in South China Sea. China Geology, 1(1), 5–16. doi: 10.31035/cg2018003.

Li SD, Sun YM, Chen WC, Yu ZC, Zhou ZM, Liu LN, Hao JM, Zhang ZB, Li X. 2019. Analyses of gas production methods and offshore production tests of natural gas hydrates. Journal of Engineering Geology, 27(1), 55–68 (in Chinese with English abstract). doi: 10.13544/j.cnki.jeg.2019-065.

Li WL, Gao DL, Yang J. 2019. Challenges and prospect of the drilling and completion technologies used for the natural gas hydrate reservoirs in sea areas. Oil Drilling and Production Technology, 41(6), 681–689 (in Chinese with English abstract).

Li YL, Hu GW, Liu CL, Wu NY, Chen Q, Liu LL, Li CF. 2017. Gravel sizing method for sand control packing in hydrate production test wells. Petroleum Exploration and Development, 44(6), 961–966. doi: 10.11698/PED.2017.06.14.

Li, Y. , Liu, L. , Jin, Y. , Wu, N. 2021. Characterization and development of natural gas hydrate in marine clayey-silt reservoirs: A review and discussion. Advances in Geo-Energy Research, 5(1), 75–86, doi: 10.46690/ager.2021.01.08.

Lijith KP, Malagar B, SiNGHs DN. 2019. A comprehensive review on the geomechanical properties of gas hydrate bearing sediments. Marine and Petroleum Geology, 104, 270–285. doi: 10.1016/j.marpetgeo.2019.03.024.

Liu QY, Tang Y. 2013. Reflections on research status of subsea test tree and home-made feasibilities. Journal of Southwest Petroleum University (Science & Technology Edition), 35(2), 1–7. doi: 10.3863/j.issn.1674-5086.2013.02.001.

Lu JS, Li DL, He Y, Shi LL, Liang DQ, Xiong YM. 2020. Study on Productivity and Sand Production of Marine Natural Gas Hydrate Development. Advances in New and Renewable Energy, 8(3), 227–233. doi: 10.3969/j.issn.2095-560X.2020.03.009.

Lu QP, Yu YJ, Xiong L, Wang SD, Yu HY. 2020. Analysics and treatment for accidents of the broken wire-Line coring pipe in reinforced deflecting. Geology and Exploration, 56(1), 445–450.

Matsuzawa M, Yoshihiro T, Hay WJ, Wingstrom L, Ayling I. 2014. A Completion System Application For the World 's First Marine Hydrate Production Test. Offshore Technology Conference

Merey Ş, Longinos SN. 2019. The gas hydrate potential of the Eastern Mediterranean basin. Bulletin of the Mineral Research and Exploration. 160, 117–134. doi: 10.19111/bulletinofmre.502275.

MH21. 2019. Japan's Methane Hydrate R&D Program-Comprehensive Report of Phase 2 & 3 Research Results. http://www.mh21japan.gr.jp/english/.

Mok J, Choi W, Seo Y. 2020. Time-dependent observation of a cage-specific guest exchange in si htdrates for CH_4 recovery and CO_2 sequestration. Chemical Engineering Journal, 389, 12434. doi: 10.1016/j.cej.2020.124434.

Moridis GJ, Collett TS, Pooladi-Darvish M, Hancock SH, Santamarina C, Boswell R, Kneafsey TJ, Rutqvist J, Kowalsky MB, Reagan MT. 2010. Chanllenges, uncertainties and issues facing gas production from hydrate deposits in geologic systems. Society of Petroleum Engineers, 14(1), 76–112. doi: 10.2118/131792-MS0.

Moridis GJ, Sloan ED. 2007. Gas production potential of disperse low-saturation hydrate accmulations in oceanic sediments. Energy Conversion and Management, 48(6), 1834–1849. doi: 10.1016/j.enconman.2007.01.023.

Ning FL, Fang XY, Li YL, Dou XF, Wang LJ, Liu ZC, Luo Q, Sun JX, Zhao YJ, Zhang Z. 2020. Research status and perspective on wellbore sand production from hydrate reservoirs. Geological Science and Technology Information, 39(1), 137–148 (in Chinese with English abstract).

Ning FL. 2005. Research on wellbore stability in gas hydrate formation. China University of Geoscience (in Chinese with English abstract). https://cdmd.cnki.com.cn/Article/CDMD-10491-2006053409.htm.

Qin XW, Lu C, Wang PK, Liang QY. 2022. Hydrate phase transition and seepage mechanism during natural gas hydrate production tests in the South China Sea: A review and prospect. Geology in China, 49(3), 749–769 (in Chinese with English abstract).

Shaibu R, Sambo C, Guo B, Dudun A. 2021. An assessment of methane gas production from natural gas hydrates: Challenges, technology and market outlook. Advances in Geo-Energy Research, 5(3), 318–332, doi: 10.46690/ager.2021.03.07.

Wan YZ, Wu NY, Hu GW, Xin X, Jin GR, Liu CL, Chen Q. 2018. Reservoir stability in the process of natural gas hydrate production by depressuriation in the shenhu area of the South China Sea. Natural Gas Industry, 5(6), 631–643. doi: 10.1016/j.ngib.2018.11.012.

Wei CF, Yan RT, Tian HH, Zhou JZ, Li WT, Ma TT, Chen P. 2020. Geotechnical problems in exploitation of natural gas hydrate: Status and challenges. Natural Gas Industry, 40(8), 116–132.

Wu NY, Li YL, Wan YZ, Sun JY, Huang L, Mao PX. 2020. Prospect of marine natural gas hydrate stimulation theory and technology system. Natural Gas Industry, 40(8), 100–115. doi: 10.3787/j.issn.1000-0976.2020.08.008.

Xin X, Wang HB, Yu H, Yuan YL, Xia YL, Zhu HX, Chen Q. 2020. Simulation-optimization coupling model for the depressurization production of marine natural gas hydrate in horizontal wells based on machine learning method. Natural Gas Industry, 40(8), 149–158.

Ye JL, Qin XW, Xie WW, Lu HL, Ma BJ, Qiu HJ, Liang JQ, Lu JA, Kuang ZG, Lu C. 2020. Main progress of the second gas hydrate trial production in the South China Sea. China Geology, 47(3), 557–568. doi: 10.12029/gc20200301.

Yoneda J, Takiguchi A, Ishibashi T, Yasui A, Mori J, Kakumoto M, Aoki K, Tenma N. 2018. Mechanical response of reservoir and well completion of the first offshore methane-hydrate production test at the Eastern Nankai Trough: A coupled thermo-hydromechanical analysis. SPE Journal, 24. doi: 10.2118/191145-PA.

Yu XH, Fu C, Hua GL, Sun L. 2019. Future alternative energy: Challenges and prospects of natural gas hydrate. Jouenal of Palaeogeography (Chinese edition), 21(1), 108–126.

Yu YJ, Lu QP, Xie WW, Lu JA, Kuang ZG, Shi HX, Xiong L, Kang DJ, Xie YF. 2021a. A communication connection method between upper completion string and lower completion string. China: CN113187469A, 2021–07-30 (in Chinese with English abstract).

Yu YJ, Lu QP, Xie WW, Shi HX, Lu JA, Kou BB, Shen KX, Ning B, Lai HF. 2021b. A sand screen which can measure the compaction settlement stress in the process of hydrate trial production test. China: CN113187446A, 2021–07-30.

Zhang W, Shao MJ, Tian QN. 2017. Technical progress of a pilot project to produce natural gas hydrate in Japanese waters. Petroleum Drilling Techniques, 45(5), 98–102 (in Chinese with English abstract). doi: 10.11911/syztjs.201705017.

Zhang XH, Lu XB, Li P. 2019. A comprehensive review in natural gas hydrate recovery methods. SCIENTIA SINICA Physica Mechanica Astronomica, 49(03), 38–59 (in Chinese with English abstract). doi: 10.1360/SSPMA2018-00212.