The Challenges and Key Technology of Drilling Safety in the Area of the Arctic

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Abstract. The Arctic is rich in oil and gas resources, which has been the focus on international oil petroleum companies presently. Understanding the challenges and key technologies of drilling safety in this area is of great importance for promoting safe and making high efficient development of oil and gas resources. Through a large number of literature research and field investigation, Arctic drilling safety key technologies as well as main research progress have been analyzed in domestic and abroad and have arrived at the following conclusions: the primary challenges for oil and gas exploration and development of Arctic include harsh operating environment, long-distance logistic support, and stringent environmental requirements. The investigation results indicate that main research directions for the Arctic oil and gas exploration and development should include long-distance icebreaker safeguard ship, ice monitoring and management system, the assessment and control of the disaster or risk, low-temperature drilling fluid system, which are the key technologies for the high efficiency and safe development of oil and gas resources in cold water area of the Arctic. Some exploratory viewpoints and recommendations for the Arctic oil and gas exploration and development on drilling safety are also proposed.

Keywords: Arctic · Drilling safety · Logistic support · Icebreaker

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1 Introduction

About 22% of the total unconfirmed conventional oil and gas in the world is buried in the Arctic region where the level of Arctic drilling technology is related to the exploration and development of Arctic oil and gas [1]. For Arctic drilling technology, drilling environmental conditions are become more complicated by factors such as ultra-low temperatures, ice floes, snowstorms, permafrost, which are prone to technical problems that are difficult to overcome in conventional drilling engineering. Therefore, Arctic drilling technology is affecting the future globally energy security [2]. The Arctic oil and gas resources are abundant. It is estimated that the Arctic oil resources account for about 25% of the world's proven crude oil reserves, and natural gas accounts for 41% of the world's natural gas reserves. It is still in the early stage of exploration. According to the US Geological Survey (USGS) report in 2009, the Arctic crude oil reserves are 120×108 m^3, and the natural gas reserves are 47×10^{14} m^3, which respectively account for 13 and 30% of the world's unrecognized resources (Figs. 1 and 2), and it is estimated that 84% of oil and gas reserves are buried in the seabed [3]. The Arctic has been discovered totally of 439 types of oil and gas fields still in 2014. It is most obviously achieved that Russia's oil and gas exploration discovered the total of 245 oil and gas fields among Arctic country, which accumulative output oil reaches 30×10^8 m^3, and gas reaches 1.11×10^{14} m^3. Thus, the Arctic oil and gas resources are an important area for future oil and gas exploration, because of it very potential and exploration prospects [4]. At present, only a few countries such as Russia, the USA, and Norway have conducted Arctic drilling operations, among which Russia has rich experience in Arctic drilling technology and operations. Although some

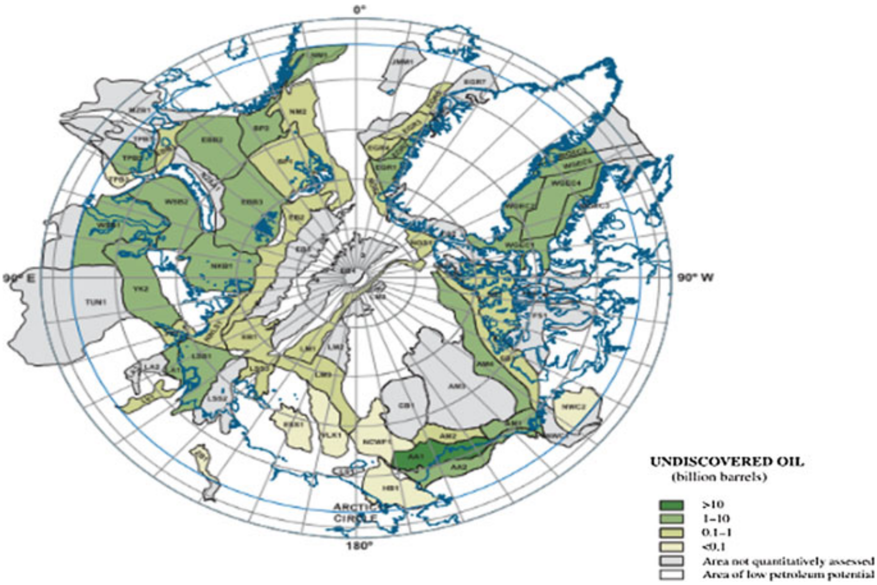

Fig. 1. Arctic oil reserve distribution map

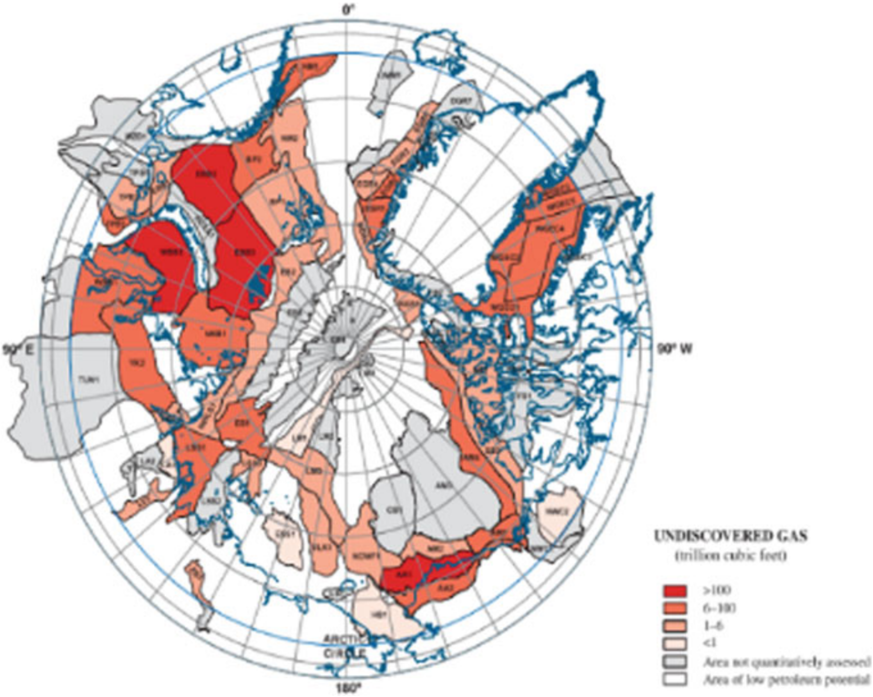

Fig. 2. Arctic natural gas reserves map

breakthroughs have been made in casing drilling, cryogenic drilling fluids, and cementing, the safety technology for Arctic drilling is not mature enough and there is deficient of systematic safety and security system. Therefore, it summarizes that the Arctic drilling faced main challenges by a large number of literature research, and which analysis of existing Arctic drilling safety critical equipment and technology status.

2 Drilling Technology Safety Challenges of Arctic

2.1 Operating Environment Challenges

Arctic offshore drilling has encountered a great safety risk in the Arctic due to the factors of extremely cold temperatures, snowstorms, and sea ice. The average annual temperature in January is between −20 and −40 °C, which not only threatens the life safety and increases the difficulty of platform operation, but also causes the rig equipment to easily undergo brittle damage and difficult to operate normally. Blizzard will cause displacement of the drilling vessel, which will cause deformation and vortex-induced vibration of the riser, posing a great challenge to its strength and safety. Ice floes also further limit the rig's loading strength and operating time [5]. The harsh environment and extremely short operating time put forward higher requirements on the reliability of shallow drilling technology and well control facilities.

2.2 Vulnerable Ecology Challenges

Because the ecology of the Arctic is vulnerable. Once a catastrophic accident occurs during shallow drilling, damage to the drilling facilities and oil and gas leaks will cause serious damage to the ecological environment. First, the Arctic region will make traditional anti-leakage technologies such as the construction of oil screens difficult to achieve, crude oil cleaning is very difficult; Second, leakage oil leads to a large number of biological deaths, while the Arctic lacking sunlight, cold weather, oil may be sealed in the ice. It is long time that environment needs to be diluted or degraded oil, which will cause long-term pollution to the population and ecological environment in the area [6].

2.3 Arctic Shallow Challenges

In the Arctic where are widely distributed the frozen sea and natural gas hydrates (Fig. 3) [2]. The permafrost region and on the seabed, natural gas hydrates exist in metastable states and are easily decomposed in the Arctic. It was generated a large amount of problems such as free gas and free water, increasing the pore pressure of the sedimentary layers, reducing the cementation strength of the seafloor formation, forming shallow gas/shallow layers. As a result, the shear strength and load carrying capacity of the gas/water deposits are reduced, possibly leading to geological disasters such as landslides and ground subsidence. Once drilled, it may also lead to gas/water impact on the wellbore and uplift, resulting in instability of wellbore and destruction of drilling facilities. In severe cases, it will lead to catastrophic accidents such as blowouts and explosions [7].

3 Arctic Drilling Safety Equipment

3.1 Icebreaker

The icebreaker is a special type of vessel used to break ice, open up navigation channels, and protect the safe operation of drilling platforms. Its characteristics include a wide body, small aspect ratio, high overall strength, and high power. The rigidity of the bow and tailwater zone is strengthened. The power plant uses a twin-shaft, multi-propeller device [8]. Icebreaking mainly involves icebreaking in two ways: (1) If the thickness of the ice layer is less than 1.5 m, “continuous” icebreaking is used to break the ice using the impact of the bow. (2) If the ice layer is thicker, the “impact type” is used to break the ice, and the bow section squeezes the ice layer to break the ice. Icebreakers are operational safety guarantees for offshore oil and gas development in the Arctic region, which related to platform safety and logistics support [9].

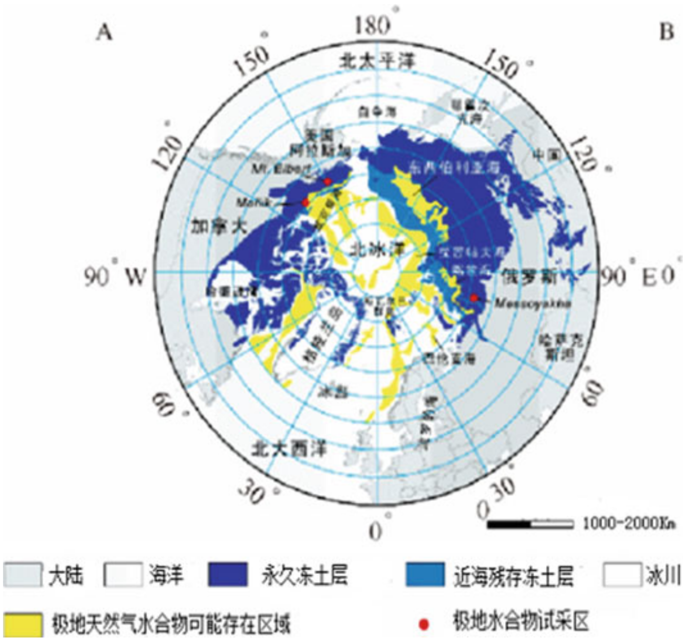

Fig. 3. Arctic permafrost and hydrate distribution map

At present, from the perspective of the number of Arctic icebreakers globally, there are about 51 icebreakers worldwide. Russia has a major advantage with 18 icebreakers, including 7 nuclear power, 7 diesel power generation, 4 shaft-line power generation diesel-electric icebreakers in Finland and Sweden; and 6 icebreakers in Canada, including 5 diesel power generation, Shaft power generation 1; USA 4 diesel power icebreaker; China, Norway, Japan, Germany are a diesel power icebreaker [10].

3.2 Arctic Remote Supply Vessel

Logistical support is critical for safe drilling operations in the Arctic, and remote supply vessels are the key to ensuring safe operations. Firstly, it is necessary to ensure the continuous supply of materials during drilling to achieve smooth development of the oil field due to the characteristics of effective drilling, short drilling time, high drilling cost, and high risk; Secondly, because of the supply vessels passing through the ice area, it is resistant to the supply vessels, load strength, icebreaking capacity and other properties put forward higher requirements [7]. Judging from available information, there are few types of Arctic supply vessels in the world, of which the representative is the ARCC (Aker Arctic Technology)-developed “ARC105” icebreaker supply vessel, which is mainly used for offshore platforms and drilling, which provide materials and equipment to perform icebreaking/ice management operations. It has preliminary fire prevention and emergency rescue capabilities. It was provided rescue and guardian services for the installation of marine structures [11].

3.3 Ice Float Monitoring System

Arctic sea ice can cover up to three-quarters of the entire area. Even in summer, at least half of the area is covered by floating ice. Ice floes, thickness up to 2–3 m, average lifespan 4a, can accumulate and form huge ice floes under the action of wind and currents, often moving for several hundred kilometers [6]. It poses a great challenge to the safety of Arctic drilling. The monitoring of ice through coastal radars, icebreakers, satellite remote sensing and other means to monitor sea ice conditions, mainly to provide reliable sea ice information for winter shipping. The exploration of oil and gas in the Arctic requires that the drilling platform maintains direction under the bad weather and the impact of ice floe. Therefore, Ice Float Monitoring System is usually used to control the ice that threatens the platform within 2 km, which mainly include ice defense systems and ice management systems [12]. The purpose of the ice defense system is to prevent ice floes threatening drilling equipment. It is predicted that the drift ice trajectory mainly through field experience, weather forecast, ice statistics, and satellite remote sensing to ensure the safe operation of the platform. Artificial observation and shipborne radar, satellite imaging and other measures provide real-time images of ice floe, tracking any ice floes that pose a potential threat to the platform. Ice management systems require the use of physical icebreaker intervention to tow, displace, or break ice floes to prevent ice floes from entering the platform's safe operating radius that is calculated by multiplying the safety pause operation time by the average drift speed of the ice floe. If the ice floe enters the penalty zone, physical intervention is initiated and the floating rig begins to transfer to the safe zone. In this case, The ice management system was started to actively destroy ice floes that entered the restricted area and the hazard level was controlled within the platform.

4 Arctic Drilling Safety Key Technologies

4.1 Low-Temperature Drilling Fluid System

In Arctic sea drilling operations, since the Arctic drilling environment temperature is below zero, it has a great influence on the rheology of the drilling fluid, which increases the viscosity of the drilling fluid and generates a gel effect, and generates high frictional resistance in the wellbore, which result the risk of large sleeve shoes being pressed open [13]. This requires that the drilling fluid must have good rheological properties, dynamic shearing force, and water loss to achieve flushing and stabilizing the wellbore. It also avoids to the heat of the drilling fluid being transferred to the formation during the cycle, which may result in the collapse of the formation. When drilling in the frozen soil if the drilling fluid has insufficient anti-low temperature capability, it will cause the fluid to freeze and lose fluidity, collapse the wellbore, and destroy the orifice. Especially when drilling natural gas hydrate formations may result in dangerous conditions such as the decomposition of natural gas hydrates and formation instability will occur.

The types of Arctic drilling fluids currently used are mainly classified into water-based and oil-based drilling fluids. The water-based drilling fluid is a drilling fluid with continuous fluid medium. It is mainly composed of low-solid polymer and solid-free polymer drilling fluid [14], which mainly composed of solid-free polymer drilling fluid, low-temperature resistant medium, borehole stabilizer, inorganic electrolyte, fluid loss reducer. Low-temperature medium mainly contains low molecular weight alcohols, such as methanol, ethanol, propanol, and other inorganic electrolyte salts as the main antifreeze. Wellbore stabilizers include polyvinyl alcohol (PVA), polyacrylamide (PAM), and the like. The inorganic electrolyte contains NaCl and KCl. Fluid loss control agents include sodium carboxymethyl cellulose (Na-CMC) and potassium humate (KHm); Oil-based drilling fluids use oil as the continuous phase, usually based on hydrocarbons such as jet fuel or diesel, add oil, ethylene glycol solution, inorganic salts, surfactants, and other substances composed of oil-based drilling fluid system [15]. However, oil-based drilling fluids have high permeability, especially in drilling cracked formations, which can cause formation pollution. With the increasing environmental protection requirements for Arctic oil development, water-based drilling fluids will gradually replace oil-based drilling fluids [9].

4.2 Shallow Layers Drilling Techniques

There are a numerous of permafrost and natural gas hydrates in the Arctic shallow stratum. As the conditions of temperature and pressure change during the drilling process, the hydrates are easily decomposed and the volume rapidly expands to resulting in drilling accidents such as kicks and blowouts, which seriously affect job safe [13]. In terms of drilling technology, gas hydrate formation drilling is dominated by decomposition suppression drilling technology that mainly increases the drilling fluid density to increase the pressure in the well, cool the drilling fluid, and adjust the relevant drilling parameters to maintain the gas hydrate phase equilibrium. It can temporarily inhibit the decomposition of natural gas hydrates though increase the hydrostatic pressure at the bottom of the well. Cooling the drilling fluid to the lowest possible temperature through a heat exchanger in the ground mud pool also suppresses the decomposition of natural gas hydrates [16]. Foreign studies have shown that by adding a certain amount of chemical reagents such as lecithin, polymer, or PVP to the drilling fluid, the drilling fluid can be adsorbed on the surface of natural gas hydrates that the rate of decomposition can be slowed down; In well control [17], the potential threats to shallow layers are dealt with mainly by optimizing well structure and designing shallow gas treatment measures before drilling, including 26 in casing piped into the shallow gas layer, using double-stage cementing to seal the shallow gas sand layer, using a plurality of blowout preventers with different sizes and pressure levels to form a BOP system, installing a diverter. Russia adopts controlled pressure drilling technology to complete safe drilling of shallow layers.

4.3 Arctic Disaster Risk Assessment and Control Technology

The key to risk assessment and control of Arctic disasters is to improve safety and reduce non-productive time. The solutions proposed by foreign companies for Arctic drilling risk control mainly include the enhancement of well control and management, which use of controlled pressure drilling technology and the strengthening of geology information analysis during drilling [18].

(1) Controlled Pressure Drilling System

This system closely monitoring the pressures of the following six operating processes to achieve drilling pressure control:

① Drilling and circulation process;
② Drilling fluid non-cyclical state (if connected to single)
③ Implementation of gate control process;
④ Casing process;
⑤ Cementing process;
⑥ Completion process.

In the case of shallow complex formations, the measurement of the downhole conditions while drilling is conducted to enhance data acquisition and processing control, which accurately predict the pressure change from the bottom of the well so that maintain the relative stability of the bottomhole pressure during the drilling process. This technology can effectively prevent the risk of shallow gas invading wellbore and shaft wall collapse, which achieve safe and efficient drilling and increase the profitability of a single well. Control pressure drilling data acquisition and processing control diagram shown in Fig. 4.

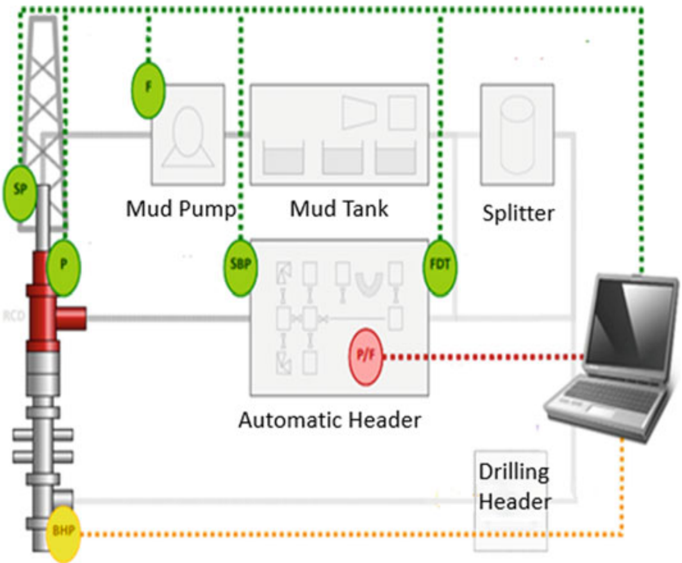

Fig. 4. Controlled drilling data acquisition and processing control schematic

(2) Drilling Geological Information Analysis System

This technology mainly consists of GC-TRACER gas analyzer, SRA source rock analysis, SRA-portable pyrolysis device (Fig. 5), gas extraction membrane device and other mobile data analysis and processing center. It can collect information and real-time analysis of cuttings during the drilling process. It also qualitative assessment of the nature of the rock, the total content of organic hydrocarbons, fluid properties, etc., which was conducted to timely obtain the characteristics of the layers. and the gas collection membrane device (Fig. 6) can analyze the downhole gas that compared with the actual gas concentration in the drilling fluid, which will predict whether there is a risk of gas uplift in the shallow layer and minimizes the geological risk [19].

Fig. 5. SRA—portable pyrolysis device

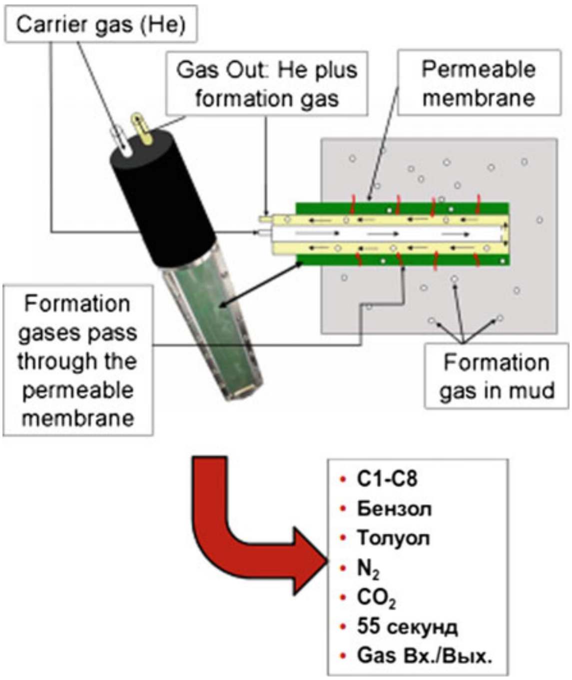

Fig. 6. Gas extraction membrane system

This technology has successfully operated more than 700 wells in the Arctic region, including more than 500 wells for stationary platform operations, more than 200 wells for semi-submersible drilling platforms, and 32 wells for power-operated drilling rigs, among which, The throttle manifold controlled by the programming controller has been well applied in the operation of 108 wells.

5 Development Trends and Prospects

Arctic oil and gas development is a huge system project. The application of Arctic drilling technology and equipment is a key factor in the successful development of Arctic oil and gas resources. The difficulties encountered in the development of the Arctic oil and gas are mainly due to high drilling costs, short working hours, and harsh environmental conditions. To solve these problems, we need to learn from the experience of successful deepwater drilling operations. In currently, the development trend of Arctic equipment includes:

(1) Research and development of drilling rigs or supply ships with strong icebreaking capabilities to enhance the replenishment capacity and ensure the successful completion of the subsequent operations.
(2) The drilling operation adopts automatic design to reduce the operator's work efficiency. Drill floor operation adopts a new type of continuous tripping device and double derrick system, which can effectively shorten the non-operation time.
(3) With the continuous development of drilling equipment automation and intelligent technologies, the development of key equipment such as Arctic special exploration/monitoring equipment, cryogenic riser systems, underwater operating robots, and dynamic positioning systems will be accelerated.
(4) The drilling equipment adopts a modular design, which is convenient for installation and maintenance and greatly reduces the construction period.

In brief, the successful exploitation of Arctic oil and gas requires the cooperation of multiple equipment technologies. Only by continuous exploration, can we solve the problems encountered in the exploration and development of Arctic oil. I believe that Arctic oil development can effectively solve global energy shortages, situation in the future.

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Author Biography

Yongqi Ma (1991–), male, master, mainly engaged in polar drilling, ocean engineering structural analysis direction.