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The Application of Well Control Technology in Drilling Process

-- Taking Tarim Oilfield as an Example

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Abstract: Tarim Oilfield, as an important petroleum base in China, faces complex drilling challenges and risks. Well control technology plays a crucial role in this context, involving various aspects such as well control design, drilling fluid technology, and well control equipment. In the geologically complex environment of Tarim Oilfield, it is necessary to develop specific well control strategies tailored to the specific situation. The application of technologies such as drilling fluid technology, well control equipment, and real-time monitoring contributes to achieving safe and efficient drilling operations. This article evaluates the effectiveness of well control technology applications, combines practical case analyses, summarizes lessons learned, and provides guidance for future technological innovation and development directions. It also provides a theoretical foundation for well control in the exploration and development of Tarim Oilfield.

Keywords: Well Control; Challenges; Strategies; Applications.

1. Introduction

1.1. Overview and Importance of Tarim Oilfield

Tarim Oilfield, located in the Xinjiang Uyghur Autonomous Region in western China, is one of the largest oil and gas-bearing basins onshore in the country. With abundant petroleum and natural gas resources, this oilfield plays a pivotal role in ensuring national energy security and promoting economic development [1]. In recent years, with the continuous deepening of exploration and development, Tarim Oilfield has become an important strategic successor area for increasing oil and gas reserves and production in China. The stable growth of its oil and gas production not only meets the growing domestic energy demand but also provides strong support for the social and economic development of the western region.

1.2. Challenges and Risks in Drilling

In the drilling process of Tarim oilfield, due to the complexity and particularity of geological conditions, there are a series of challenges and risks. Firstly, the oilfield is located in a high-temperature and high-pressure environment, which puts forward high requirements for the high-temperature and high-pressure performance of drilling equipment. Secondly, there are a large number of complex structures such as faults, fractures and karst caves in the stratum, which bring great difficulties to the drilling construction. In addition, oil and gas reservoirs are often adjacent to high-pressure water or gas layers, which significantly increases the risk of well surge, blowout and other accidents. At the same time, there may be dangerous situations such as toxic and harmful gas leakage, stratum collapse and so on in the drilling process, which seriously threaten the life safety of personnel on site.

1.3. Definition of Well Control Technology and Its Key Role in Drilling

Well control technology, that is, oil and gas well pressure control technology, is an indispensable part of drilling engineering. It uses special well control equipment and means to maintain the balance between formation pressure and wellbore fluid column pressure during downhole operations, aiming to prevent and control potential risks such as blowout and kick [2]. In the drilling process, well control technology is not only related to the protection of oil and gas resources and the sustainable development of the environment, but also the key factor to ensure the safety and efficiency of drilling operations. By accurately controlling formation and wellbore pressures, well control technology can significantly reduce drilling risk and improve operational efficiency, while ensuring accurate geological data for subsequent oil and gas development. With the continuous improvement of the management system of petroleum industry, well control technology plays an increasingly prominent role in ensuring the safe production of oil fields, and becomes an indispensable security measure for oil field units.

2. Geological Characteristics and Drilling Challenges of Tarim Oilfield

2.1. Brief Description of Geological Environment of Tarim Oilfield

Tarim Basin is a large oil and gas bearing area with multi-age and multi-type basin superimposed compound, with multi-age oil source rocks and abundant oil and gas resources. The basin is surrounded by the Tianshan, Kunlun and Altun Mountains, and in the middle is the Taklimakan Desert, the largest mobile desert in the world. [3] The oil and gas resources in the basin mainly exist in the Cambrian, Middle and Upper Ordovician, Carboniferous and Triassic Jurassic

strata, and the existence of these high abundance source rocks has laid the material foundation for the oil and gas exploration in the Tarim Basin.

2.1.1. Reservoir Depth

Reservoirs in Tarim Oilfield are generally buried deep and there are a large number of ultra-deep Wells. In the process of ultra-deep well drilling, formation pressure and temperature will change significantly with the increase of well depth, which puts forward higher requirements for drilling equipment and drilling fluid properties. At the same time, ultra-deep Wells are prone to complex situations such as wellbore instability, loss and blowout, which increase the difficulty and risk of drilling.

2.1.2. Geological Structure

The Tarim oilfield is characterized by complex geological structures, such as faults, folds and fractures. These geological structures not only affect the migration and accumulation of oil and gas, but also bring uncertainty to drilling engineering. In the process of drilling, it is necessary to accurately judge and deal with these geological structures to ensure the smooth progress of drilling.

2.1.3. Rock Characteristics

The geological rock characteristics of Tarim oilfield are mainly characterized by complex distribution of carbonate rocks and clastic rocks. Carbonate rock, mainly limestone, has the characteristics of compact, strong rigidity and chemical origin, and is the main place for oil and gas accumulation. The clastic rock is relatively loose, mainly composed of sand, mud and other particles. In the Tarim oilfield, these two rock types often appear alternately, forming a complex reservoir structure. Carbonate reservoirs are usually developed with fractures and caverns, and are highly heterogeneous, which brings great challenges to oil and gas exploration and development [8]. The clastic rock reservoir is relatively homogeneous, but there may be some problems such as unstable distribution of sand bodies and high shaliness content. In addition, there are many sedimentary facies types in Tarim oilfield, including Marine facies and continental facies. The development of these sedimentary facies types is closely related to the characteristics of rocks, which together control the distribution and enrichment of oil and gas. In general, the geological rock characteristics of Tarim oilfield are complex and diverse, the alternate emergence of carbonate rock and clastic rock and the development of various sedimentary facies make the oil and gas exploration and development in this area more challenging and risky.

3. The Main Technical Problems in The Drilling Process

Due to the special geological environment of Tarim oilfield, a series of technical problems are faced in the course of drilling. Here are the main ones:

(1)High temperature and pressure environment

The oil and gas reservoirs in Tarim oilfield are in high temperature and high pressure environment, which puts forward high requirements for the high temperature and high pressure resistance of drilling equipment. At the same time, high temperature and high pressure environment will also affect the performance and stability of drilling fluid, increasing the difficulty and risk of drilling.

(2)Complex formation condition

The formation conditions in Tarim oilfield are complex and changeable, including the hard and soft interleaved strata, the high permeability strata and the easily lost strata. These complex formation conditions bring great challenges to wellbore stability and pressure control during drilling.

(3)Wall stability problem

Wellbore stability is a prominent problem in the drilling process of Tarim Oilfield. Because of the complexity of strata and the mechanical properties of rock, the shaft wall is prone to collapse, falling block and other phenomena, and even lead to stuck drilling, buried drilling and other accidents. Therefore, maintaining wellbore stability is an important task in the drilling process of Tarim Oilfield.

In order to cope with these challenges, a series of technical measures and management methods have been adopted in the drilling engineering of Tarim Oilfield. For example, optimizing drilling fluid properties for high temperature and pressure environments; Adopt advanced drilling equipment and technology to improve drilling efficiency [4]; Strengthen monitoring and early warning of wellbore stability. The implementation of these measures effectively reduces the drilling risk and improves the drilling success rate.

4. Application of Well Control Technology in Drilling Process

4.1. Well Control Design and Management Strategy

Table 1. Main points of Tarim drilling operation

Serial number	Operation phase	Key design/process
1	design	Well structure, casing design, drilling target zone density design
2	Drilling phase	Drilling: conventional drilling, controlled pressure drilling Trip: Controlled pressure trip Circulation: reconstruction cycle, throttling cycle Emergency treatment: overflow, leakage, high casing pressure, hydrogen sulfide, abnormal high pressure disposal
3	Old well preparation completion stage	Electrical measurement, string running, drilling, wellhead replacement, well killing
4	Daily management	Well control equipment maintenance, fire, explosion and hydrogen sulfide prevention, emergency supplies, well control degree implementation, winter insulation, acceptance

In the drilling process of Tarim Oilfield, well control design and management strategy are very important. Table 3-1 shows the main points of conventional well control in Tarim oilfield. First, preventive well control design is key to ensuring drilling safety. Potential well control risks can be predicted and identified through a comprehensive analysis of geological data, engineering data and historical experience. On this basis, specific well control measures are formulated, such as

reasonable design of well structure, selection of appropriate drilling fluid density, etc., in order to prevent the occurrence of kicks, blowout and other accidents. Second, risk assessment and management are an important part of well control design and management. Through qualitative and quantitative analysis methods, various risks that may be encountered in the drilling process are assessed, such as abnormal formation pressure, toxic and harmful gas leakage, etc. According to the results of risk assessment, formulate corresponding risk response measures and emergency plans to ensure timely and effective disposal when abnormal situations occur.

4.2. Application of Drilling Fluid Technology in Well control

Drilling fluid technology is one of the core components of well control technology. In the drilling process of Tarim Oilfield, the performance requirements of drilling fluids are very strict. First, the drilling fluid needs to have a good rock carrying capacity in order to carry the cuttings generated during the drilling process out of the wellbore in a timely manner to prevent the accumulation of cuttings leading to downhole complications. Second, the drilling fluid needs to have good lubrication properties to reduce friction between the bit and the wall and improve drilling efficiency. In addition, the drilling fluid also needs to have good high-temperature and high-pressure resistance, inhibition performance and environmental protection performance. In order to meet these performance requirements, the drilling fluid system needs to be selected and optimized. The drilling fluid system suitable for the geological characteristics and drilling requirements of Tarim oilfield is selected through comparative test and analysis and evaluation of the properties of different drilling fluid systems. At the same time, according to the actual situation in the drilling process, the performance of drilling fluid is adjusted and optimized in real time to ensure that the drilling fluid always maintains a good performance state.

4.3. Well Control Equipment and Operation Techniques

Well control equipment and operation technology are important means to ensure drilling safety. In the drilling process of Tarim oilfield, the main well control equipment includes blowout preventer system, well killing and throttling equipment. These devices play a vital role in the prevention and treatment of kicks, blowouts and other accidents. As the core part of well control equipment, the blowout preventer system can quickly close the wellhead in case of kick and prevent the formation fluid from flowing into the wellbore without control. For example, the rotary control head is often used in the drilling process in the Tarim area. The rotary control head is one of the wellhead blowout preventer groups that can realize controlled pressure trip and rotary drilling. It can realize the rotary sealing of other drill pipe, drill pipe, drill collar and other kinds of drill tools, and is an important wellhead tool to achieve underbalance and controlled pressure drilling. Its structure is shown in Figure 1. At present, the rotating control head in the oilfield is mainly FX35-17.5/35. Kill and throttling equipment is used to control the wellhead back pressure and regulate the pressure balance in the well to prevent wall instability and further influx of formation fluids. In terms of operational technology, the well control equipment needs to be properly installed, commissioned and maintained. At the same time, operators need to be proficient in well control equipment operation skills and emergency plans, in order to be able to quickly and accurately deal with abnormal conditions.

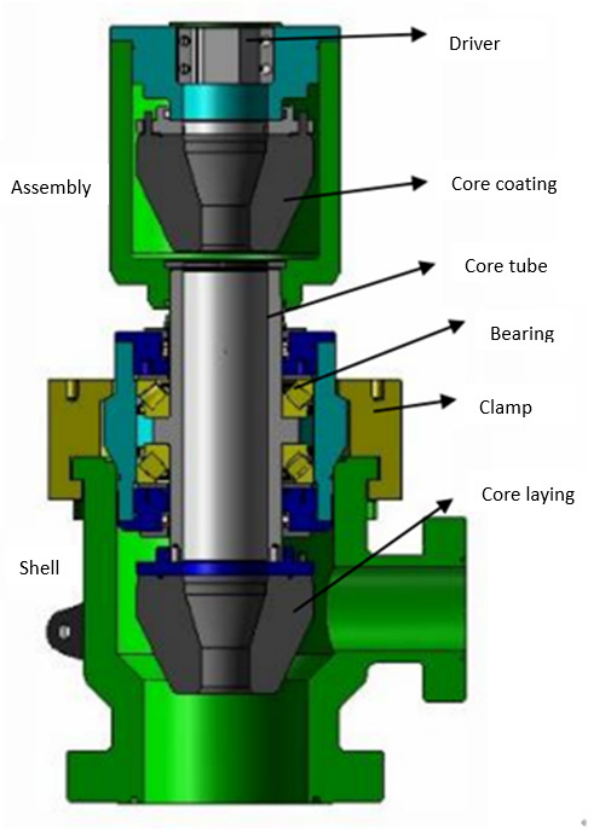

Fig 1. Structure of the rotating control head

4.4. Application of Real-Time Monitoring and Decision Support System in Well Control

Real-time monitoring and decision support system is widely used in well control. By installing sensors and monitoring systems, various parameters can be monitored in real time during drilling, such as wellhead pressure, drilling fluid properties, formation pressure, etc. These data can timely reflect the abnormal conditions in the drilling process and provide scientific basis for well control decision. Data analysis and early warning system is an important tool for in-depth analysis and processing of real-time monitoring data. Through data mining and analysis, potential well control risks can be identified and early warning information can be issued in advance. This helps to take targeted measures to prevent and deal with well control risks in advance, reducing the probability of occurrence.

Decision support process is a process that provides auxiliary support for well control decision based on real-time monitoring and data analysis. Through collecting and analyzing all kinds of relevant information, combining expert knowledge and experience to judge and reason, finally get scientific and reasonable well control decision recommendations. This helps improve the accuracy and timeliness of well control decisions to ensure safe and smooth drilling.

5. Application Effect Evaluation and Case Analysis of Well control Technology

In the drilling practice of Tarim Oilfield, the application

effect of well control technology is directly related to the safety, efficiency and economic benefit of drilling engineering. In order to objectively evaluate the application effect of well control technology, this paper proposes a series of evaluation indicators, combined with the in-depth analysis of typical cases, in order to sum up the experience and lessons, and put forward improvement suggestions to optimize the future well control practice.

5.1. Evaluation Index of Well Control Technology Application Effect

Evaluating the effectiveness of well control technology requires a comprehensive consideration of several aspects, including safety indicators, efficiency indicators and economic benefits indicators. Safety indicators: mainly measure the effectiveness of well control technology in preventing blowout, kick and other accidents, such as the number of accidents, accident severity, etc. Safety index is the primary standard to evaluate the effect of well control technology, which reflects the guarantee degree of technology to drilling safety. Efficiency indicators: Mainly evaluate the impact of well control technology on drilling efficiency, including drilling cycle, drilling speed, equipment utilization, etc. Efficiency indicators reflect the role of well control techniques in improving the efficiency of drilling operations. Economic benefit index: The economic effect of well control technology is evaluated from the perspective of cost saving and revenue increase, including drilling cost, oil and gas production, and comprehensive economic benefit. Economic benefit index is an important basis for evaluating the comprehensive application effect of well control technology.

5.2. Typical Case Analysis

In order to show the application effect of well control technology more specifically, this paper selected a typical case of Talimu oilfield for analysis. Taking a well in Manshen block of Tarim as an example, the target layer of this well belongs to carbonate reservoir with overflow and leakage. The maximum predicted formation pressure is 92.75MPa, and it belongs to the development well with 70MPa≤ predicted formation pressure < 105MPa. The risk of reservoir leakage and overflow is high, and the predicted H2S content is 130-5900mg /m3. Due to the complex geological conditions, there are high-pressure oil and gas reservoirs, the predicted formation pressure of 92.5MPa, the well control risk is high. This well has a large well control risk during the operation in the target zone. According to the Implementation Rules for Well control of Drilling in Tarim Oilfield (2021 edition), this well is a first-level well control risk during the operation in the target zone. The well head well control device as shown in Figure 2 was used in the operation of the target zone in the four openings of the well. Through the application of advanced well control technology, including the optimization of drilling fluid performance, the use of efficient blowout preventer system, real-time monitoring of downhole parameters, etc., the wellhead pressure was successfully controlled and the blowout accident was prevented. The case illustrates the effectiveness of well control techniques in dealing with complex geology and high-pressure oil and gas formations. Challenges and solutions: During a drilling operation, the problem of wellbore instability was encountered in a high-temperature and high-pressure environment. By adjusting the drilling fluid formulation, optimizing the well structure design, strengthening the stability monitoring of the well wall and other measures, the challenge has been successfully met to ensure the smooth drilling operation. This case demonstrates the flexibility and utility of well control technology in solving specific drilling problems.

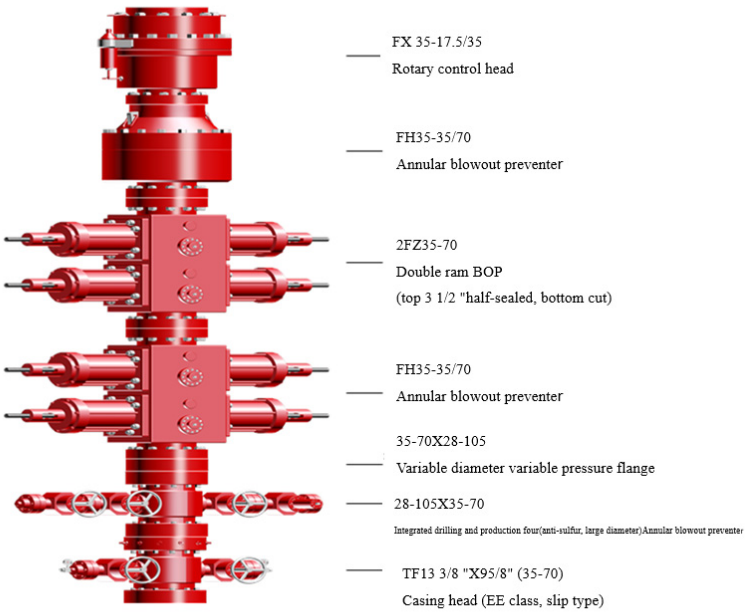

Fig 2. Structure of the rotating control head

5.3. Lessons Learned and Suggestions for Improvement

Through the analysis of typical cases, this paper summarizes the following lessons and suggestions for improvement:

Lessons learned: First, the application of well control technology needs to fully consider the complexity and

uncertainty of geological conditions, and achieve local conditions. Second, the implementation of well control technology requires close coordination and collaboration between departments to ensure the effective implementation of various measures. Finally, training and drills in well control techniques are critical to improving the ability to respond to emergencies.

Improvement suggestions: In view of the challenges and problems faced by the current well control technology, this paper puts forward the following suggestions: First, strengthen the research and development and innovation of well control technology, improve the adaptability and reliability of technology; Second, strengthen the training of well control technology and personnel training to improve the overall quality of well control team; The third is to improve the management system and emergency plan of well control technology to improve the ability to respond to emergencies.

To sum up, well control technology plays an important role in the drilling process of Tarim oilfield. By objectively evaluating its application effect and summing up the experience and lessons, we can continuously optimize and improve the well control technology system, and provide more safe, efficient and economical guarantee for the drilling engineering of Tarim oilfield.

6. Challenges and Future Development Direction

With the deepening of exploration and development of Tarim Oilfield, the geological environment and technical requirements of drilling engineering are becoming more and more complex. As the core means to ensure drilling safety, well control technology is increasingly clear about its challenges and future development direction.

6.1. Current Well Control Technology Challenges

First of all, the increase of ultra-deep Wells, high temperature and high-pressure Wells and other complex well types in Tarim Oilfield have put forward higher requirements for the high temperature and high-pressure resistance performance of well control equipment [5]. The performance stability and reliability of existing well control equipment under high temperature and pressure environment are faced with severe challenges. Secondly, complex and changeable geological conditions, such as fractured reservoirs and highly permeable formations, make the problems of pressure control and wellbore stability more prominent in the process of well control. How to deal with these geological conditions effectively and prevent blowout, kick and other accidents is an important challenge facing the current well control technology. Finally, with the increasingly stringent environmental requirements, how to ensure the safety of drilling, reduce the impact of drilling fluid on the environment, and achieve green drilling, is also an important issue that needs to be solved by the current well control technology.

6.2. Technological Innovation and Development Trend

In the face of the above challenges, well control technology must be continuously innovated and developed to meet the needs of the drilling engineering in the Tarim oilfield. The future development of well control technology will show the following trends: Intelligent well control system: With the continuous development of artificial intelligence, big data and other technologies, intelligent well control system will become an important development direction of future well control technology. Through real-time monitoring, automatic analysis, intelligent decision-making and other means to achieve accurate control of the drilling process, improve well control efficiency and safety. Form-preserving drilling fluid technology: In order to meet environmental requirements, future drilling fluid technology will pay more attention to environmental performance. Through the development of a new environmentally friendly drilling fluid system, the pollution and damage of drilling fluid to the environment can be reduced and green drilling can be achieved. High Performance well control equipment: To improve the performance stability and reliability of well control equipment, more efficient well control equipment will be developed in the future. These units will have improved resistance to high temperatures and pressures, as well as better sealing and corrosion resistance to meet the drilling needs of complex well types.

6.3. Industry Cooperation and Policy Advice

In the face of well control technology challenges and trends, industry collaboration and policy support are also critical. It is suggested to strengthen the cooperation and exchange between domestic and foreign oil companies, research institutes and equipment manufacturers to jointly develop and promote advanced well control technology. At the same time, the government should issue relevant policies to encourage and support the innovation and development of well control technology, so as to provide more safe, environmentally friendly and efficient well control technology guarantee for the drilling project of Tarim oilfield. To sum up, although the current well control technology in Tallimu oilfield faces many challenges, with the continuous innovation and development of technology, as well as the strengthening of industry cooperation and policy support, it is believed that well control technology will be able to better adapt to the needs of drilling engineering in Tallimu oilfield in the future, and play a more important role in ensuring drilling safety, improving drilling efficiency and achieving green drilling.

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