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Research Article

Optimization and Application of Wax Removal Technology for Fixed Tubing String in Offshore Wells

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Abstract

This study focuses on the selection and application of wax removal techniques tailored for fixed tubing columns in offshore wells that have been obstructed by wax deposits. Initially, the paper delves into the importance of well decommissioning and examines prevalent decommissioning techniques, outlining their respective advantages and limitations. Subsequently, three distinct unblocking technologies are proposed, tailored to address different causes and scenarios of well clogging: physical plugging removal technology, chemical treatment technology, and mechanical unblocking technology. Each technology is thoroughly analyzed, discussing their applicable scopes, operational procedures, equipment and anticipated effectiveness in removing blockages. To validate the feasibility and practicality of these proposed unblocking methods, an actual offshore well case study is conducted. The results demonstrate that thermal nitrogen wax removal technology emerges as the most effective approach, necessitating further optimization of its application. The paper then details the oil-filed implementation of this technology, including methods for generating hot nitrogen and its subsequent application. Following the implementation, significant improvements in wax removal and unblocking are observed, attesting to the technology's effectiveness. The findings of this study offer valuable insights and practical guidance for addressing wax blockage issues in fixed tubing columns of offshore oil wells. By providing a comprehensive analysis of different unblocking techniques and their application in oil-filed, this paper contributes to enhancing the efficiency and reliability of offshore oil production operations.

Keywords

Waxing, Unblocking, Hot Nitrogen Gas Artificial, Cable-through Packer, Fluid Drainage, Field Applications, Fixed Tubing String

1. Introduction

During the production of oil wells, the mixture crude oil is transported from underground to the surface. This process involves the expansion of dissolved gases within the crude oil [1], which leads to fluctuations in temperature and pressure within the production tubing. These changes result in a decrease in the solubility of waxes within the crude oil mixture, causing the waxes to gradually precipitate [2]. The precipitated waxes, due to their different molecular weights, are adsorbed onto sucker rods, pumps, or the necks of the tubing gradually as the temperature and pressure change. The high viscosity of these precipitated waxes adhere to the inner walls of the tubing, narrowing the internal diameter and increasing flow resistance. This situation will reduce the amount of crude oil produced, potentially leading to well

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shutdowns if the tubing becomes blocked. Wax formation is a significant issue that causes damage to a large number of oil wells annually. Consequently, oil fields incur significant costs to wax cleaning and unblocking operations during the development process.

The wax accumulation issue in oil wells has led to extensive research on wax removal technologies globally. The earliest explorations in oil well dewaxing technology date back to the 1960s, primarily focusing on mechanical unblocking technology and the hot oil method [3, 4]. Mechanical unblocking technology employs mechanical devices to eliminate wax from the exterior of fuel lines, primarily utilizing tools like wax scrapers and wax removing drills. The hot oil method involves circulating high-temperature oil through the oil pipe. This elevated temperature causes the deposited wax to melt, allowing it to flow back to the surface along with the liquid.

As technology progressed, chemical treatment technology and physical wax removal methods were developed. The chemical method primarily involves adding specific chemicals to the oil well. These chemicals lower the crystallization temperature of the wax, preventing its precipitation during the production process or promoting the formation of a softer wax that's easier to remove from the tubing wall.

The physical technique for removing wax blockages includes ultrasonic wax prevention [5] and electrothermal wax cleaning [6]. Ultrasonic wax prevention utilizes the vibrational energy of ultrasonic waves to prevent the aggregation of wax particles by inducing uneven sizing. The electrothermal method for cleaning wax employs the thermal effect generated by an electric current to elevate the temperature of the oil pipe, thereby preventing deposition or facilitating melting of already deposited wax.

Concurrently, mechanical wax cleaning has also evolved. One approach involves a continuous oil pipe carrying a flushing head, enabling rapid downward entry for mechanical scraping of wax. Additionally, this continuous oil pipe can serve as a circulating pipe column for chemical wax dissolution [7-9].

Due to wax formation, pipe structure, and oil well production technology, not all wax removal technologies are suitable for oil filed applications. Some waxing techniques have been phased out due to environmental, effectiveness, and cost considerations. However, with the advancement of tools, chimerical materials, and equipment technology, some waxing techniques have been significantly improved, particularly those that are environmentally friendly and efficient.

In this study, the selection of wax removal technology for a wax-affected offshore oil well is the focus. By analyzing the advantages, disadvantages, and adaptability of different wax removal techniques, while considering various factors such as environmental impact, cost-effectiveness, and operational feasibility, field applications have been conducted, and they have yielded promising results. This research aims to provide insights into determining the optimal wax removal strategies for offshore oil wells.

2. Brief Description of Target Wells

The target well is an exploration well in a newly developed offshore block, with an inclined depth of 4,460m and a vertical depth of 3,221m. For efficient production, an integrated perforating, testing and completion string structure is adopted. The completion string assembly in the well from bottom to top is as follows: perforating gun + Φ73mm thickened chamfered tubing + over cable packer + Φ73mm thickened tubing + safety valve + Φ73mm thickened tubing + tubing hangers.

Because this well is the first in the block, no subsea oil and gas pipeline has been established yet. Crude oil transportation relies on shuttle services between the oil platform and the oil tanker terminal. During adverse weather, the well is temporarily shut down and the tanker returned to the dock anchorage. This shut-in period leads to a decrease in wellbore temperature and increases the possibility of wax formation. To ensure normal production, the target well undergoes mechanically scraped and waxed twice per shift during routine operations.

After a recent shutdown and subsequent resumption of production, the well exhibited no production output and lost its self-flowing capability. This led to suspicions of a wax plug formation within the tubing. Prior to the shutdown, the daily oil production was $38m^3$; the daily gas production ranged from 16,000 to $21,000m^3$; the oil pressure was 3.26MPa, and the casing pressure was 5.41MPa.

To restore the well's self-flowing production, the nitrogen annulus air lift technology was initially applied. Nitrogen was injected from the casing head, entered the casing annulus through the annular air vent valve of the cable packer, and flowed into the tubing from the perforating gun position. This recovery operation was successful in resuming production. However, a few days later, after another shutdown due to weather issues, the well once again lost its self-flowing capability.

Subsequently, nitrogen gas lift was used again in an attempt to restore the well to the self-flowing state, but the operation was unsuccessful. After that, a mechanical wax removal method was attempted to clear any wax blockage in the tubing, but the wax removal tool failed to clear the blockage. Following this operation, a detailed analysis of well conditions and production data was carried out to determine the root cause of the self-injection failure. Additionally, measures such as chemical treatment or thermal wax removal are being considered to address the issue and restore the well to its full productive capacity.

3. Preferred Wax Removal Technology

3.1. Challenges in Implementing Wax Removal Methods

3.1.1. Tubing Column Shrinkage Hinders Tool Insertion

Upon examining the tubing column tool instruction manual, it was identified that shrinkage occurs at critical points, including tubing suspension, downhole safety valve, and over cable packer. This situation is illustrated in Figure 1. While the overall internal diameter of the tubing column is 76mm, the most significant shrinkage measures only 62mm. By analyzing the temperature profile of the wellbore, as shown in Figure 2, and integrating crude oil physical property data, it is surmised that wax accumulation is most likely to occur between 500 and 550 meters. These shrinkage locations, situated above the potential waxing zone, present considerable obstacles for for oil extraction machinery and wax-clearing tools, which must navigate through these constricted areas, especially where wax formation is most prevalent.

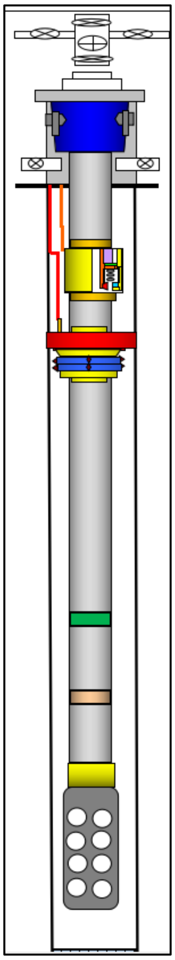

Figure 1. Schematic diagram of pipe column structure.

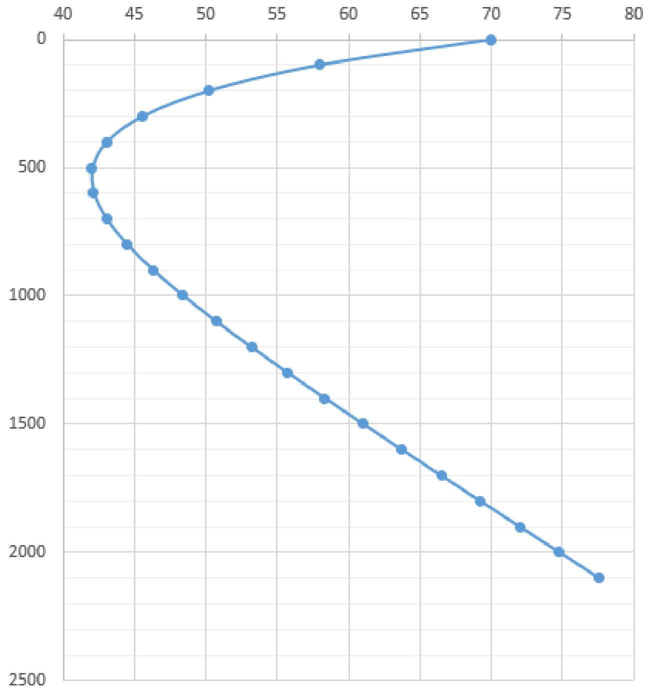

Figure 2. Wellbore temperature distribution curve.

3.1.2. The Through-cable Packer Has a Small Annular Flow Area and Low Temperature Resistance of the Rubber Seal

When adopting hot washing wax methods, the hot fluid must traverse the cable-through packer. The packer vent valve, which serves as the sole flow channel on the cable-through packer, has a limited flow area of approximately 8~9cm^2, thereby restricting the flow capacity. If the pump pressure is increased, excessive pressure will cause damage to the packer vent valve, potentially preventing its complete closure in subsequent stages. Therefore, during operation, it is crucial to maintain a moderate injection speed to prevent damage to the packer vent valve. Additionally, the pressure and temperature range of the rubber cylinder on the cable-through packer is limited. Exposure to high-temperature and high-pressure hot nitrogen may result in damage to the rubber cylinder. Therefore, the application of hot washing and wax unblocking methods necessitates careful consideration of pump pressure and injection speeds.

3.1.3. The Location of the Fish in the Tubing String Cannot Be Determined

During operations in the original well tubing string, metal rods accidentally fall into the wellbore, with their precise locations remaining indeterminate. This poses significant challenges, as the presence of these fish prevents the use of continuous tubing for well decongestion. The blockage caused by these fallen objects disrupts the smooth execution of subsequent unblocking measures, adding complexity and difficulty to the process.

In such scenarios, thermal decommissioning technology emerges as a viable and often the only feasible option. This approach offers several advantages: it avoids potential damage to the oil wells, eliminates the need for tubing up and down operations, and can be implemented without disrupting normal production activities. Consequently, thermal decommissioning not only addresses the technical challenges but also ensures operational efficiency and safety.

3.2. Selection and Optimization of Wax Removal Technology

Given the limitations of the original well tubing string, mechanical wax removal within the tubing is largely impractical. Therefore, the primary focus for wax removal in blocked wells is on annulus hot washing cleaning technology. Currently, there exist two primary methods for wax removal: circulating hot water cleaning and steam circulation unblocking [10]. Both approaches are thermodynamic-based, utilizing heated tubing strings to reach a certain temperature. This allows solidified wax to redissolve and resume flow, thus effectively unblocking the well.

Hot water circulation cleaning involves heating fresh water to temperatures ranging from 80 to 100 ℃ using boilers. Subsequently, pumps are utilized to circulate this hot water from the annulus into the wellbore. Once inside the wellbore, the hot water effectively melts and dissolves wax, gums, and other materials that cause blockages. These dissolved materials are then flushed out of the tubing alongside the hot water [11, 12].

Nitrogen circulating heating unblocking employs the permeability of nitrogen active gas to dissolve, expand, and extrude plugged materials within oil wells, effectively removing blockages. This process, along with hot water recirculation cleaning, shares the benefit of not damaging the reservoir. Both methods can clear wax and unblock tubing without interrupting normal production, effectively removing wax, gum, scale, and other blockages. This restores the wells' normal production capacity and is applicable to various types of oil wells, new and old, for both maintenance and repair. These processes are notably easy to implement, often relying solely on simple heating operations at the site.

While hot water cleaning and hot nitrogen recirculation decommissioning share many similarities, they exhibit distinct characteristics when analyzed for specific well applications:

1) Compared with hot water and hot nitrogen, hot water has a higher heat capacity and can release more heat per unit volume. In terms of energy density and heat transfer, hot water cycle unblocking is faster than nitrogen cycle heating.
2) Nitrogen has compressibility, according to the situation of the blockage can quickly carry heat to the location of the blockage, hot water at atmospheric pressure is considered incompressible, mobility is worse than nitrogen, if the blockage is more serious, it is easy to inject pressure is too high, the cycle of obstruction, the flow of nitrogen resistance is small and can be compressed, in terms of mobility, nitrogen cycle unblocking effect is better.
3) The hot water circulation unblocking process can improve the temperature and add chemical agents to change the unblocking performance of hot water, nitrogen unblocking performance can only be improved by increasing the temperature, although the highest heating temperature of nitrogen can be heated up to 450℃, but the method is relatively single, from the view of unblocking of the diversity of the hot water circulation unblocking process is more widely applicable.
4) Nitrogen cycle plugging is non-chemical corrosive, and non-combustible, non-explosive, compared with hot water, safer and more reliable and less impact on the column.

This plugging is injected from the casing annulus, through the cable packer exhaust valve and then into the oil casing annulus, from the bottom of the tubing to the inside of the tubing. From the structural characteristics of this well and the circulating channel of the annulus and the sealing structure of the tubing column, hot nitrogen is more suitable than hot water for the unblocking of this well, and hot nitrogen has the advantages of high efficiency and fast dissipation for unblocking of blockage without circulating channel, which can realize fast unblocking and fast liquid discharge, and is also conducive to the hot recovery of thick oil and the role of wax clearing and unblocking of the tubing column.

4. Field Application of Wax Cleaning Process

There are two ways to obtain nitrogen at offshore, one is liquid nitrogen and the other is membrane nitrogen production. Owing to the complexities and substantial expenses associated with transporting liquid nitrogen, on-site nitrogen production is favored for offshore operations. At present, the main process of nitrogen production is membrane nitrogen, nitrogen membrane group is a cylindrical hollow fiber membrane bundles, each bundle contains millions of hollow fibers to provide the maximum separation area, each fiber diameter of about tens of microns, just like a human hair as fine. Compressed air enters from one end of the fiber bundle, gas molecules under pressure, first contact in the high pressure side of the membrane, followed by adsorption, dissolution, diffusion, desolvation, escape. The permeation rate of each gas is different, the permeation rate of oxygen, carbon dioxide, water vapor, etc. is fast, and it is exuded from the fiber wall of the high-pressure inner side to the low-pressure outer side, and discharged from the opening of one side of the membrane module; the nitrogen with a small permeation rate is enriched in the high-pressure inner side, and is discharged from the other end of the membrane module, which realizes the separation of nitrogen, and the purity of nitrogen separation is generally more than 99% [14, 15].

There are two ways to get hot nitrogen, one way is to use special hot nitrogen heating tools, which can heat up to 300 degrees Celsius; the other is to use the heat generated by the nitrogen equipment itself to heat the separated nitrogen, which can realize the recycling of energy consumption, but the temperature of its heating is limited, usually at 60~90 degrees Celsius. For the target wells, considering the temperature resistance of the packer cartridge and the dissolution temperature of the caking wax, the tail gas heating method can meet the temperature demand.

After the nitrogen equipment was put in place, firstly, the top of cable packer was emptied to the annulus air body at the wellhead, in order to prepare for the annulus air tightness test. After the pressure release, the casing pressure gauge was installed to monitor the change of casing pressure and to verify the sealing status of the venting valve closure, and then the high-pressure nitrogen injection pipeline at the wellhead and the casing annulus were tested step by step up to 27.5MPa, and the pressure was stabilized for 10 minutes, and after the test pressure was qualified, the hot nitrogen annulus was de-plugging process was carried out. The total amount of hot nitrogen injected into the annulus was 3200m^3, the pressure of nitrogen injection was stabilized at 6.3-6.5MPa, and the temperature of hot nitrogen was maintained at 53.1-74.5℃. After lifting through, the well was put into spraying production, and the spraying was successfully induced.

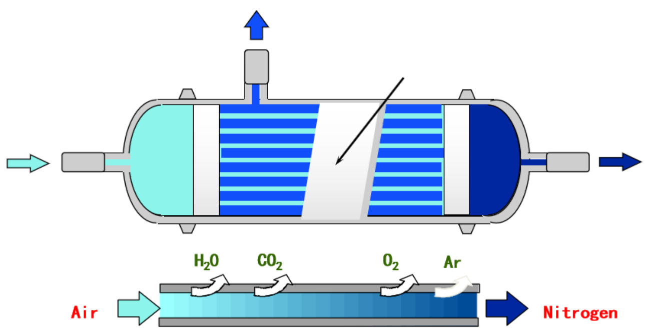

Figure 3. *Membrane Nitrogen Generation Nitrogen Generation Schematic.*

5. Conclusions and Recommendations

1. Given the significant operational costs associated with offshore platforms, the selection of liquid discharge methods should prioritize rapid and efficient liquid discharge during the commissioning of offshore oil test wells and the resumption of oil well self-flowing production. Among various wax removal methods, hot nitrogen technology offers economic and temporal advantages, despite the higher initial equipment costs. Its ability to enhance wax removal efficiency and reduce platform occupation time justifies its active promotion and application in offshore oil test well completions.
2. The hot nitrogen max removal technology has emerged as a novel and practical solution for promptly restoring production in thick oil and aged wells affected by wax plugging. Boasting simplicity, safety, and straightforward operation, this method presents an appealing alternative for rapid and efficient recovery.
3. The application of hot nitrogen wax removal technology extends beyond conventional wells, encompassing horizontal, directional, large displacement, and multi-branch wells. Its implementation addresses the challenges associated with rapid and efficient drainage in horizontal wells, which can be difficult to tackle using traditional methods.

Acknowledgments

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Conflicts of Interest

No potential conflict of interest was reported by the authors.

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