Research and Practice of Visual Detection Technology for Water Outlet Point of Oil Well

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Abstract. The casing corrosion problem in Changqing Oil Region has long troubled oilfield development which caused a serious loss of production capacity. For a large number of corroded perforated wells, the accurate identification of the water outlet has always been a key technical problem in the process of casing damaged well management. In order to solve this technical problem, this paper presents a method of visualizing logging with nitrogen gas lift negative pressure to locate the water outlet point of casing damaged wells. This method uses a nitrogen booster to inject pressurized nitrogen into the annular space of the oil well to occupy the space in the wellbore with the nitrogen volume and its expanded volume after decompression. By displacing the fluid in the well to create a negative pressure in the wellbore, making the pressure in the wellbore near the leak point lower than the formation pressure, and the formation fluid flowing into the wellbore through the leak point, Finally, use a visual detector to observe the flow direction, fluid state and tube wall conditions of the well fluid in the wellbore in real time. Quickly and accurately locate to position the location of water outlet point of casing damaged wells. The field test results showed that this method can quickly and effectively locate the water outlet point of casing damaged, the test results are intuitive, reliable, and with high location precision.

Keywords: Nitrogen gas lift · Visual logging · Water entry detecting

1 Introduction

The Changqing Oil Region is located in the Type I and Type II corrosion areas in Ordos Basin. Affected by the shallow aquifer of the area and the high corrosion ions in the produced fluid, the casing damage is common in oil wells [1, 2]. In the initial stage of new well construction in Changqing Oilfield, a series of anti-corrosion measures have been taken and it worked very well. The probability of casing damage has been kept at a low level. However, with the continuous development, the corrosion problems of oil and water well casings have become increasingly prominent, and a large number of casing damaged wells had presented serious challenges to the stable production of

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oil fields. Water inflow problems caused by casing damage in oil wells have caused increased water cuts and reduced oil production. Most wells contain 100% water cut, which seriously affected production [3–5]. To this end, the oilfield company has established a special management project team and invested special funds to realize special management and reproduction for those casing damaged wells which are flooded and closed. The management of casing damaged wells is divided into two kinds: the conventional management and the long-term management. The former adopts the usual packer mining which has the general defect of short validity period. When the casing is corroded and the scale is serious, it is easy to invalidate the packer and affect the isolation packer mining effect [6–8]. The latter adopts long-acting packer or casing blockage or chemical blockage maintenance methods to block or pack water or leakage points to resume production [9–12]. The technical difficulty lies in accurately identifying the location of the water outlet. Traditional engineering logging cannot determine the water outlet, while the packer sealing has a long cycle and low positioning accuracy, especially when the casing is severely corroded, scaled or deformed. Therefore, the accurate outlet positioning of casing damaged well is an urgent technical problem that needs to be solved.

Since the inception of special treatment of casing damaged wells in Changqing Oilfield, new technologies for outlet positioning have been proposed successively and new technology trials have been launched one after another. At this time, the VideoLog visual inspection method was also proposed. In the first stage, a field test of 6 wells was carried out in Changqing Oilfield. Though the experiments at this stage have not yet fully achieved the expected results, it has increased people's understanding of the new technology of visual inspection of oil wells, deepened the judging level of the well outlet, and promoted the establishment of a new technology project in the second stage of nitrogen lift negative pressure visual detection technology to locate the water outlet point. All of those efforts have laid a solid foundation for subsequent testing in process methods, technical equipment and construction experience.

2 Visual Inspection Technology for Oil and Gas Wells

Oil and gas well visual inspection technology, which is developed exclusively for the special working environment in oil and gas wells, is a general term for downhole video acquisition, transmission, surface video processing technology and equipment [13]. The early visual inspection equipment for oil and gas wells was called “Downhole Video (DHV)” [14]. Traditional DHV is divided into two categories, one is “hawkeye DHV” which is similar to downhole camera [15], using well logging cables to transmit downhole images; the other is “optical fiber DHV”, which use optical fiber to transmit smooth video in real time [16]. The hawkeye DHV is operated by a common single-core logging cable car, which has a low image transmission frame rate and large transmission delay, but portable and environmental adaptability underground. Optical fiber DHV is smooth and the transmission delay is small, but a special optical fiber logging cable car is required, which has poor adaptability and reliability in underground with high temperature, high pressure, and sulfur-containing environment.

VideoLog oil and gas well visualization detection technology can use ordinary logging cables to transmit smooth color video in real time, which has strong adaptability. On a 5000 m ordinary seven-core armored logging cable, the transmission rate is up to 2 Mbps. It possess both the advantages of fiber-optic downhole TV video and hawkeye DHV, which can eliminate the maximum uncertainty of downhole problems and improve the pertinence and effectiveness of downhole operation measures. It is a new generation of visual logging technology equipment [17]. As shown in Fig. 1 below, it is the downhole color image obtained by VideoLog visual inspection.

（a） Casing coupling （b） Perforation （c） Damaged casing

（d） Severe fouling（Can't tell if there is a broken casing） (e) Broken casing（There is no way to judge whether it is a water entry) （f） Perforation leaking oil droplets)

Fig. 1. The downhole color image obtained by VideoLog visual inspection

Foreign research data shows that there are many application fields of downhole video inspection, which can be roughly divided into two categories: one is mechanical inspection, such as fish top inspection, tubing encounter card, casing encounter resistance, etc., accounting for about 80%; the other is fluid Inlet detection which is usually used to locate the water outlet and then perform the water shutoff, accounting for about 20%. The technical challenge of water outlet detection of casing damaged wells in Changqing Oilfield belongs to the field of fluid inlet detection. Therefore, the "VideoLog visual leak detection technology for oil wells" was proposed as a new technology test project for finding water outlets in oil wells and was approved by new technology pilot project. The visual inspection test of water outlet was operated in six wells. This experiment is the first in domestic. Although the tests have not yet completely achieved the expected results, many valuable experiences and conclusions have been gained.

Supported by appropriate pre-test preparation measures (Well cleanup, drifting and scraping), VideoLog visual logging can obtain clear and smooth downhole video data, intuitively and comprehensively grasp the most real and reliable information downhole. (Due to the unsatisfactory application of hawkeye DHV in domestic, before the test, a common view was that visual detection could not obtain clear and valuable data in the oil well).

The static detection is difficult to accurately locate the casing breakage and water outlet point in shutdown, the reasons are as follows:

(1) In the production status, there is an inability to lower the visual inspection tool. During the detection, the oil well must be ceased and lift out the production string.
(2) When detecting, the oil well is in shutdown, in the pressure equilibrium and no fluid will be produced.
(3) The fluid lacks fluidity when the pressure in the well is in equilibrium., It is difficult for the visual inspection to capture the characteristics of producing water from the broken casing.
(4) When the well wall is seriously scaled, it is difficult to accurately judge whether the casing is damaged based on the well wall images.
(5) Due to the well fluid lacks of fluidity, there is no way to determine whether the damaged casing is producing water.

Therefore, in order to accurately locate the position of water outlet point of casing damaged, appropriate technical measures must be taken to disrupt the pressure balance in the wellbore, so that the fluid flows out from the casing damaged position, and a flow pattern is generated in the wellbore.

Combining the above statements with the investigation and research of the gas lift process, it can be concluded that the nitrogen gas lift process can produce a flow state in the wellbore, and the visual logging tool can be laid down from the inside of the pipe string to achieve simultaneous testing and gas lifting. Therefore, the method of visually detecting the water outlet point of the oil well with nitrogen gas lift is proposed and supported by the project of Changqing Oil and Gas Research Institute.

3 Nitrogen Gas Lift Negative Pressure Detection Technology at the Water Outlet of Oil Well

3.1 Technical Principles

Nitrogen gas lift uses a nitrogen booster to inject pressurized nitrogen into the annular space of the oil well and then squeeze the fluid. When the casing pressure was greater than the tubing static column pressure, the inner-tubing fluid level will rise. If the nitrogen was introduced to the tubing from the bottom, by occupying the wellbore space with wellbore the nitrogen volume and its expanded volume after decompression, the fluid level will sharply rise and displace the fluid in the well to create a negative pressure in the wellbore. At this time, the pressure in the wellbore that near the leak point was lower than the formation pressure, and the formation fluid flowing into the wellbore through the leak point. Finally, using a visual detector to make a real-time inspection of the flow direction, fluid state and tube wall conditions of the well fluid in the wellbore and thereby locate to position of water outlet point of casing damaged wells quickly and accurately.

The basic principle of oil well gas lift logging is shown in Fig. 2. The formation is regarded as an area of infinity, and the energy of the formation can be counted as a constant value. The pump truck pressurizes the nitrogen which was provided by the nitrogen truck, and then injects nitrogen into the well from the annulus of the oil jacket. Under the effect of pressure, the well fluid is lifted to the surface through the gas lift pipe string, and then enters the liquid storage tank. Gas lift refers to pressure the annular space of the oil jacket through the tubing, and then discharge the liquid above the bell mouth of the oil pipe. Generally, the gas lift is regarded as the ideal state for Gas lift water detecting logging technology.

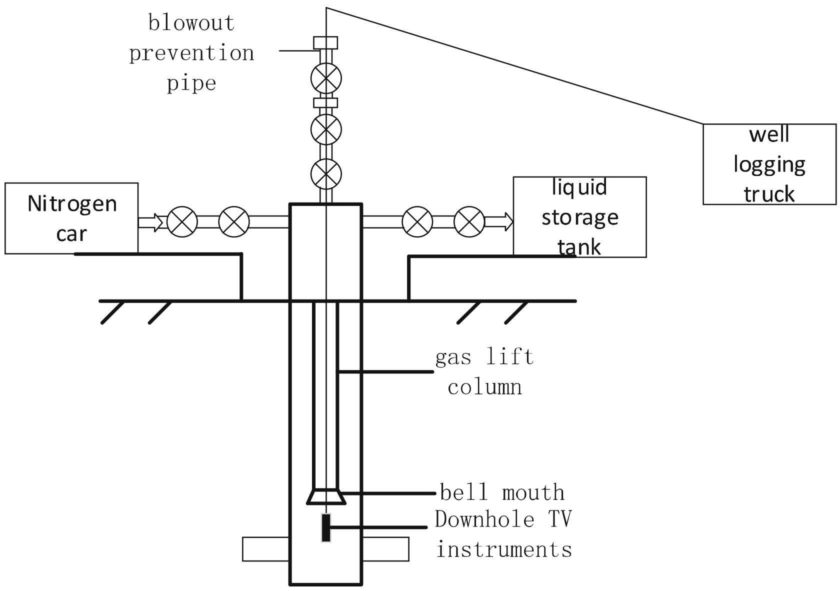

Fig. 2. Schematic diagram of gas lift logging principle

The gas lift pressure needed in the ideal state is:

$$P_1 \geq \frac{H_\rho}{100} \tag{1}$$

In the formula: P_1 - the pressure required in lifting, MPa; H_1 - the lowering depth of gas lift string, m; ρ - the fluid density in the well, g/cm^3.

It is difficult to achieve this ideal state in practical logging. Therefore, in gas lifting, as much as possible to discharge liquid is considered as a relatively ideal state. The required gas lift pressure is:

$$P_2 \geq \frac{1 + d^2/\left[(D-2h_1)^2-(d+2h_2)^2\right]}{100} \cdot H_2\rho \tag{2}$$

In the formula: P_2 - the required gas lift pressure when discharging fluid from the wellhead, MPa; D - casing outer diameter, m; h_1 - casing wall thickness, m; d - tubing inner diameter, m; h2 - tubing wall thickness, m; H_2 - depth of liquid level, m.

After the gas lift is completed and the pressure is relieved, there is a certain pressure difference between the formation pressure and the pressure which was formed by the fluid in the well in the special case of no formation fluid.

$$\Delta p \geq \frac{4Q\rho}{100(D-2h_1)^2 \cdot \pi} \tag{3}$$

In the formula: ΔP - pressure difference, MPa; Q - the volume of liquid discharged from the wellhead during the gas lift, m^3.

If there is a casing breakout point in the oil well, when the gas lift completed the pressure release, a negative pressure will form in the wellbore, the casing breakout point will produce water and the liquid level will rise. In the process of pressure recovery, the VideoLog new logging cables visual detector with color and full frame can be used to make real-time observation of the liquid flow direction and state in the wellbore and the status of the pipe wall, which can quickly and accurately find the location of the water breakout.

3.2 Process Equipment

Liquid nitrogen trucks, pump trucks, seven-core cable logging trucks, oil and gas well visualization logging tools (contains special water indicator for oil well leak detection) and surface systems. Figure 3 is the site equipment and construction pictures, Fig. 3(a) is a photo taken by the visualization tool before entering the wellhead, Fig. 3(b) is the liquid nitrogen truck and pump truck used in the on-site nitrogen gas lift. The main technical indicators of oil and gas well visual logging tools are shown in Table 1, the temperature resistance in the table indicates that the highest temperature resistance index of the instrument is 150 °C, pressure resistance means the highest pressure index that the instrument can withstand is 70 MPa, the video frame rate means that the downhole instrument transmits 25 pictures to the surface display instrument in one second.

a The instrument goes into the wellhead

b Liquid nitrogen trucks and pump trucks

Fig. 3. Equipment at the construction site

Table 1. Main technical indicators of VideoLog visual logging tool

Outer diameter /mm	Length /mm	Temperature resistance /°C	Withstand voltage /MPa	Video frame rate /f/s	Image resolution	Image transmission
54	2370	150	70	25	640 × 360	Continuous image transmission to the ground in real time

3.3 Test Process

To ensure the possibility in the wellbore, the first step is drifting. In this process, the wellbore is circulated and cleaned with tons of clean water. The well fluid is replaced with clean water to improve the light transmission condition of the well fluid and facilitate the visual inspection. Then, a bridge plug is punched above the perforation section to block the pay zone, and a pressure leak test is carried out. Secondly, a negative pressure is generated in the wellbore through the nitrogen gas lift technology to produce liquid at the broken position and create a fluid state in the wellbore. Finally, maintaining the negative pressure in the wellbore, a seven-core cable logging truck was lowered to the visualization detector to monitor the flow state and direction of well fluid, and track and locate the water outlet point of casing damaged.

4 Project Example

4.1 Test Process Well XX1 in Changqing Oilfield

4.2 Construction Process

The lowering depth of gas lift pipe string is 760.2 m with a bell mouth at the front of the pipe. The visual logging device is lowered from the bottom of tubing, and the detection is performed during the lowering process. The initial liquid level is located at 25.6 m. When the device is lowered near the bell mouth, the gas lift is started. The lift pressure is 5 Mpa. After the lift pressure is released, the device is lowered at a constant speed of (300–500) m/h. When observe the damage inside the casing, the water direction indicator should be observed simultaneously to monitor the direction of water flow, track and locate the water outlet. The detective range is 760 m–1460 m, many casing breaks and water outlets are found.

4.3 Test Results

In the 844 m–865 m, the casing damage is serious; three broken positions are confirmed in 846.1 m, 859.3 m, 864.3 m. Something unusual are found in the casing break point, the lateral drift of the water indicator indicates that the water bursting out from the sleeve (Fig. 4).

Fig. 4. Leak detection result of Well XX1 in Changqing Oilfield

4.4 Well XX2 in Changqing Oilfield

Construction Process

The lowering depth of the gas lift pipe string is 1280 m, with a bell mouth at the front of the pipe. The visual logging device is lowered from the bottom of tubing. The distance between the initial liquid level and the wellhead is 6.12 m. When the device comes out of the bell mouth, the gas lift is started. The lift pressure is 11.2 MPa. After the lift pressure is released, the device is lowered at a constant speed of (300–500) m/h. Observing the damage of the inner wall of the casing. The water direction indicator should be observed simultaneously to monitor the direction of water flow, and track and locate the water point. The detective range is 1280 m–1880 m, the casing breakage and water outlet are found.

Test Results

In the range of 1379 m–1381 m, the transmittance of the well fluid was good. The abnormal and turbulent vortex water flow was found. The water indicator moves laterally. The casing wall was broken. It can be confirmed as the water outlet position of the damaged casing (Fig. 5).

（a）Broken casing （b）Turbulent vortex flow

Fig. 5. Leak detection result of Well XX2 in Changqing Oilfield

5 Conclusion

Through the analysis and summary of the field tests of the two wells as well as the verification of the follow-up measures, the following conclusions are drawn:

(1) This article proposes for the first time that the visual detection technology is combined with nitrogen gas lift to locate the water outlet point of a casing damaged well. This method is the first in China and has achieved good results. The author of this article is the main designer of the method, and the main person in charge of the detection process in wells XX1 and XX2, responsible for testing and operating the instruments, and analyzing the detection results.
(2) Gas lift is the premise and foundation for finding the leak location. The structure of the gas lifting pipe string, the depth and pressure of lowering must be properly designed to ensure a safe lifting. After the pressure is released, a negative pressure

can be effectively formed in the wellbore, so that the leakage point has liquid discharged.

(3) The smooth video is very important for judging the direction of water flow, and the effect of the water direction indicator on leakage point is very obvious. The visual logging tool obtains smooth downhole video images in real time through the logging cable, and cooperates with the water indicator to effectively track and accurately locate the broken water point of the sleeve.

(4) After the negative pressure is formed in the wellbore, the water near the outlet have a high transmittance. Combined with the scouring effect of the water flow, the wellbore in the outlet section has an excellent view, and the imaging is clear. The direction indicator floats laterally, indicating the leak location. The upward flow of well fluid indicates that there is a water outlet point below; the turbulent flow in the wellbore shows that there is a water outlet point nearby; the static well fluid means that there is no water outlet point below.

(5) The actual application results of the two wells showed that the nitrogen lift negative pressure visual leak detection is an effective leak detection technology for oil well casing, which has the value of engineering application and spread.

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