Plugging Performance Evaluation of Nanoemulsion in Ultrafine Drilling and Completion Fluid by Pressure Conduction Method

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Abstract. The paper is proposed to introduce nanoemulsion into the ultra-drilling completion fluid system to improve the plugging performance. The pressure conduction method was used to evaluate the plugging properties of tight sandstone, the evaluation results showed that the fluid loss of ultrafine drilling and completion fluid with nanoemulsion was reduced to 6.3 mL, and the pressure difference between the upstream and downstream reaches 0.29 MPa. Plugging Property of ultrafine drilling and completion fluid with nanoemulsion is double higher than without nanoemulsion, and was 2.96 times higher than only nanoemulsion. The nano-emulsion and micro-nano solid particles in the ultrafine drilling fluid can seal the plugging layer after entering the pore throat, it can play a role in retarding pressure transmission and filtrate intrusion, and enhancing the plugging effect. The experimental results provide a certain reference value for the follow-up study of the sealing properties of the nanoemulsion.

Keywords: Pressure conduction; Nanoemulsion; Ultrafine drilling and completion fluid; Plugging; Tight sandstone.

1. Introduction
The ultra-deep tight sandstone gas reservoirs in the Tarim Oilfield have extremely low permeability, micro/nano size pore throats are developed. During the drilling and completion process, the traditional plugging materials are hard to enter the pore throats and form effective seals. Plugging, it is difficult to prevent pressure transmission and filtrate intrusion, reservoirs are easily damaged seriously and borehole wall is unstable, oil and gas reservoirs are unable to be effectively developed. In recent years, micro/nano plugging materials such as ultrafine calcium, micro silicon, nano polymer, carbon nano material and nano emulsion etc. [1-4], through the adsorption, bridging and deformable filling function of micro and nano particles, it is possible to form a tight pressure-blocking layer on the well wall to stable borehole Wall.

The ultrafine drilling and completion fluid discussed in this paper is a system without bentonite. The application of more than ten wells in field indicated that ultrafine drilling and completion fluid (ρ=1.75 and 2.10g/cm³) used successfully more than 20d at 160 ℃ underground without precipitation during drilling, all of the case wells acquired high oil and gas output. The drilling fluid weighted by ultra-fine barite can achieve self-suspension. In this system, there is no plugging fluid loss material, and the amount of fluid loss is too large, which leads to the system easily invades the formation and causes pollution when there is a large pressure difference, so nanoemulsion is introduced to improve the plugging performance of ultrafine drilling and completion fluids.
At present, the evaluation methods for the blocking effect of nanoparticles in drilling and completion fluids mainly include high temperature and high pressure filtration loss measurement, high pressure water measurement of mud cake permeability experiment, scanning electron microscope observation method, sound wave transmission rate measurement and pressure conduction method, etc. [5-6], many studies have shown that the pressure conduction method can better reflect the blocking effect of nano-particles with high accuracy.

2. Experimental Samples

Samples for this indoor evaluation experiment include core blocks in the Keshen area of Tarim Oilfield, brine (4%NaCl), self-made nanoemulsion and ultrafine drilling and completion fluids.

2.1. Core

The sandstone rock samples in the Keshen area of the Tarim Oilfield used in the experiment are dense, its matrix permeability is low, the storage space type is mainly mixed intergranular pores, the correlation between pore and permeability is poor, and micro-sized pore throats are developed. The basic physical properties of sandstone rock samples are shown in Table 1.

| number | depth /m | Porosity | Permeability /mD | Mineral composition |
|--------|----------|----------|-----------------|-------------------|
|        |          |          |                 | quartz Plagioclase Potash Feldspar Clay mineral |
| 18-2   | 6230     | 3.92%    | 0.00304         | 65.9 18.9 3.6 5.5 |
| 18-3   | 6254     | 6.21%    | 0.00908         | 67.0 18.0 9.7 4.5 |
| 18-4   | 6482     | 4.36%    | 0.00713         | 55.6 21.7 15.2 6.5 |

2.2. Nanoemulsion

The self-made nanoemulsion used in the laboratory experiment is a transparent and uniform system with thermal stability [7]. Its particle size is mainly concentrated at about 10nm (as shown in Figure 1). The dosage is 0.2%, the surface tension of the nanoemulsion drops to 33 mN / m, the interfacial tension is only 4.34 mN / m, and the Zeta potential is -32.4mV. The nanoemulsion has good wetting, spreading and permeability. In the capillaries and tiny pore throats of tight sandstone, the core permeability is reduced and a tight and effective sealing layer is formed.

2.3. Ultrafine Drilling and Completion Fluids

Ultrafine drilling and completion fluids was a novel completion fluid, which was composed of ultrafine heavier material, stabilizing agents, dispersants and so on. The size distribution of ultrafine drilling and completion fluids $D_{50}$ was less than 1μm, and $D_{90}$ was less than 3μm. Because of the tiny size effect and surface effect of the ultrafine powder, these particles could be suspended in liquid by the Brownian motion; and stabilizing agents, dispersants could effectively enhanced repulsion among the ultrafine barite particles, so as to achieve stable dispersion for a long time. In conclusion, ultrafine drilling and completion fluids had good dispersion, suspension, high-thermo stability, rheology, and
reduced wear and tear on the drill string. The performance of ultrafine drilling and completion fluids with different densities is shown in Table 2. Under the dual action of electrostatic repulsion and Brownian motion, ultrafine drilling and completion fluids can form a dynamic stability system. The samples were aging for 10 days at 180°C, then cooled to room temperature and measured its rheology.

**Table 2. The basic performance of Ultrafine drilling and completion fluids**

| Density (g/cm³) | Test method | Test condition | AV (mPa·s) | PV (mPa·s) | YP (Pa) | Gels (Pa/ Pa) | Compaction degree (N) |
|----------------|-------------|----------------|------------|------------|---------|---------------|-----------------------|
| 1.80           | Before aging | Test after continuous aging 20days | Normal temperature | 13         | 9        | 4           | 5/5.5                  | 0.09                  |
|                |             | 180°C/10days |            | 10.5       | 8        | 2.5          | 1/7.5                  | 0.5                   |
| 2.10           | Before aging | Test after continuous aging 20days | Normal temperature | 27         | 23       | 4           | 4/8                   | 0.33                  |
|                |             | 180°C/10days |            | 23         | 22       | 1           | 1.5/6                  | 0.87                  |

The results in Table 2 show that rheological property of two samples had little changed, stability performance was good after stilling 10 days at 180°C. In the experiment, the 2.1 g/cm³ ultrafine drilling and completion fluid was added with nanoemulsion for plugging performance evaluation. The performance of the ultrafine drilling and completion fluids before and after adding the nanoemulsion are shown in Table 3. It can be seen that, after adding 0.2% nanoemulsion, the ultra-drilling completion fluid has good rheological properties, API fluid loss is reduced by 6.3 mL, the fluid loss performance of ultrafine drilling and completion fluids has been improved.

**Table 3. Basic performance of ultrafine drilling and completion fluid**

| Sample                                | Density / (g/cm³) | AV / (mPa·s) | PV / (mPa·s) | YP /Pa | G10s/G10min/ (Pa/Pa) | API fluid loss/(mL) |
|---------------------------------------|-------------------|--------------|--------------|--------|----------------------|---------------------|
| Ultrafine drilling and completion fluids | 2.10              | 23           | 22           | 1      | 1.5/6                | 18.7                |
| Ultrafine drilling and completion fluids +0.2% Nanoemulsion | 2.10              | 23.5         | 23           | 0.5    | 0.5/4.5              | 12.4                |

3. Experimental Method
In this experiment, a pressure transmission instrument based on the pressure pulse method independently designed and developed by China Petroleum University (Beijing) Reservoir Reconstruction Center (see Figure 2) is used. It is an ultra-low permeability core permeability tester designed and manufactured according to the principle of unsteady state method, the instrument is composed of liquid storage tank, core holder, thermostat and data acquisition and transmission system [8-10]. Due to the low permeability of tight sandstone, it is difficult for conventional core flow devices to drive the core to obtain a stable permeability. The pressure conduction method calculates the permeability by measuring the change of the downstream pressure with time when the fluid flows through the core. The results are accurate and efficient.
Figure 2. Pressure transmission instrument and core flakes

The basic principle of the pressure transmission method is to establish an initial pressure difference between the upstream and downstream of the core, and to monitor the pressure change of the downstream closed fluid in real time, where the upstream is the fluid to be measured and the downstream is simulated formation water [11-13]. A fixed fluid pressure is added to the upper end of the core slice, and the upstream fluid which is measured seeps through the core to the closed downstream, and the change in downstream pressure is recorded. The better the fluid blockage of the fluid to be tested, the slower the flow rate of the fluid in the core, the longer the downstream pressure rise time, and the slower the rise rate; conversely, the worse the fluid blockage of the fluid to be tested, the faster the fluid flow rate in the core. The downstream pressure rise time is short and the rise speed is fast. The core permeability $K$ [14-15] from formula (1). The core permeability $K$ [14-15] is given by formula (1).

$$K = \left( \frac{\lambda \mu CVL}{-A} \right)$$

$K$——Core permeability, mD;
$\lambda$——the slope of the plate of the relationship between ln $[(Pm-P(L, t)) / (Pm-Po)]$ and time $t$
$\mu$——Upstream fluid viscosity, mpa.s;
$C$——Downstream fluid compressibility, Mpa;
$V$——Downstream volume of core, cm³;
$L$——Sheet thickness, cm;
$A$——Cross-sectional area of core sheet, cm².

4. Results and Discussion

4.1. Evaluation of Three Fluid Plugging Effects

Before evaluating the plugging effect of nanoemulsion in ultrafine drilling and completion fluids, the plugging effect of three basic fluids are firstly evaluated for subsequent reference and comparison. The three basic fluids are respectively 5% saline, ultra-drilling and completion fluids filtrate and 0.2% nanoemulsion. Compared with ultrafine drilling and completion fluids, these three basic fluids are pure liquid fluids without solid phase, which are relied on droplets to enter the pore throat of the core to form a single material blockage. In the experiment, it is firstly set the downstream pressure to 0.05 MPa, after the flow is stabilized, and then the flow pressure is added to 1.04 MPa. The displacement pump is set to constant pressure mode and the downstream pressure change is recorded. The pump stopped finally until the downstream pressure no longer changes. The evaluation of the plugging effect of the three fluids is shown in Figure 3-5.
According to the slope $\lambda$ of the three fluid pressure transfer curves obtained in Fig.4-6 and relevant parameters, the core permeability is calculated by formula (1). The results of evaluation experiments of the three fluid plugging effect are shown in Table 4.
Table 4. Results of evaluation experimental of three fluid plugging effects

| Fluid                          | Permeability /\(\text{mD}\) | Pressure difference between upstream and downstream/MPa | Penetration time /s |
|-------------------------------|-------------------------------|--------------------------------------------------------|---------------------|
| Brine                         | \(0.657 \times 10^{-3}\)     | 0.008                                                  | 725                 |
| Ultra-micro drilling completion fluid filtrate | \(0.507 \times 10^{-3}\)     | 0.038                                                  | 780                 |
| Nanoemulsion                  | \(0.334 \times 10^{-3}\)     | 0.098                                                  | 835                 |

Based on the results of plugging evaluation of the pressure conduction experiment in Table 3, it can be seen that: (1) Due to the osmotic pressure difference and the hydraulic effect between the upstream and downstream of the core, the downstream pressure gradually increases with time, and the downstream pressure will reach a fixed stable value, the better the fluid plugging effect, the longer the time required for the downstream pressure to reach the stable value, and the greater the pressure difference between the downstream pressure value and the upstream pressure value after stabilization; (2) When the experimental fluid is brine, the pressure of downstream fluid rises rapidly, and the downstream pressure tends to stabilize after 725 s. At this time, the pressure difference between the upstream and downstream is only 0.008 MPa, it is indicated that the pressure at the upper and lower ends of the core is close to the same under the action of brine, and the brine has not formed an effective seal in the pore Plugging; (3) When the experimental fluids are ultrafine drilling and completion fluid filtrate and nanoemulsion, the downstream pressure reaches a stable value and increases 55s and 90s respectively compared with brine, and the pressure difference between upstream and downstream is greater than 0.008 MPa, it is indicated that ultrafine completion fluid filtrate And nanoemulsion has better plugging effect than saline.

4.2. Evaluation of Plugging Effect of Ultrafine Drilling and Completion Fluids

Figure 6 shows the evaluation results of the plugging effect of the ultrafine drilling and completion fluids with a density of 2.1 g / cm\(^3\). The experimental procedure is the same as Section 4.1. After the 865s, the downstream pressure tends to be stable. At this time, the core permeability is calculated to be \(0.276 \times 10^{-3}\) mD, and the pressure difference between the upstream and downstream is 0.14 MPa.

4.3. Evaluation of Plugging Effect of Nanoemulsion in Ultrafine Drilling and Completion Fluid

Figure 7 shows the evaluation results of the plugging effect of the ultrafine drilling and completion fluids contain 0.2 % nanoemulsion with a density of 2.1 g / cm\(^3\). The experimental procedure is the same as Section 4.1. After 930 s, the downstream pressure tends to be stable. At this time, the core permeability is calculated to be \(0.979 \times 10^{-4}\)mD, and the pressure difference between upstream and downstream is 0.29 MPa.
The pressure transfer curves of Figures 6 and 7 are synthesized to obtain the evaluation of the plugging effect before and after the nanoemulsion is added to the ultrafine drilling completion fluid. The experimental results are shown in Figure 9.

According to the results of plugging evaluation of the pressure conduction test in Table 5, it can be seen that: (1) When the experimental fluid is ultrafine drilling and completion fluids, the upstream and downstream pressure difference reaches a stable value of 0.14 MPa when the downstream pressure is stable. The pressure difference is 1.43 times higher than nanoemulsion which is 0.098 MPa, and the penetration time increases by 30s, It is indicated that the ultrafine drilling completion fluid has a better plugging effect than the nano-emulsion, and the plugging effect is achieved by a certain amount of micro-nano solid particles in the ultrafine drilling fluid enter the core pores;

(2) When the experimental fluid is ultrafine drilling and completion fluid with nanoemulsion, the
pressure difference between upstream and downstream reaches 0.29 MPa when the downstream pressure reaches a stable value. The time is increased by 2.96 times, and the penetration time is increased by 65s, it is indicated that, after the nano-emulsion is added, the micro-nano solid particles in the nano-emulsion and the ultrafine drilling fluids enter the core pores at the same time, the micro-nano solid particles can be gradually filled and forms a sealing plug layer, which plays a role in retarding the pressure transmission and filtrate intrusion, and enhancing the plugging effect. This can be confirmed by the SEM image of the core end surface after the experiment (Figure 9); (3) When the ultrafine drilling and completion fluids with nanoemulsion are the experimental fluids, the core permeability decreases by an order of magnitude when the test pressure is stable, is only $0.979 \times 10^{-4}$ mD, which also confirms the plugging effect of the nanoemulsion.

5. Conclusion
1) The pressure conduction method calculates the permeability by measuring the change of the downstream pressure with time when the fluid flows through the core. The better the fluid sealing property, the slower the flow rate in the core, the longer the downstream pressure rise time, and the higher difference between the upstream and downstream pressure, the method has a short period and high efficiency.
2) When the experimental fluid is a nanoemulsion, the downstream pressure reaches a stable value when it is increased by 90 s compared with brine, and the pressure difference between upstream and downstream is greater than 0.008 MPa, it is indicated that the nanoemulsion has a certain blocking effect.
3) After adding nanoemulsion to the ultrafine drilling and completion fluids, the fluid loss decreased by 6.3 mL, the core permeability decreased to $0.979 \times 10^{-4}$ mD, and the pressure difference between the upstream and downstream reaches 0.29 MPa, the pressure difference is doubled higher than ultrafine drilling and completion fluids, is 2.96 times higher than nanoemulsion. After the nanoemulsion and the micro-nano solid particles in the ultrafine drilling fluid enter the pore throat, they can be filled, compacted step by step, and then form a sealing plugging layer, which plays a role in retarding the pressure transmission and filtrate intrusion, and enhancing the plugging effect.
4) The pressure conduction method is used to evaluate the plugging performance before and after adding nanoemulsion in the ultrafine drilling and completion fluid, and the difference in plugging effect can be clearly seen. This method provides a certain reference value for the subsequent research on the plugging properties of nanoemulsion.

Acknowledgment
This work was financially supported by Tarim Oilfield Project "Study on Formation Characteristics and Technical Countermeasures of Drilling Fluid in Yingsha and Yulong Blocks" (Project No. 201019121044) and the Strategic Cooperation Technology Projects of CNPC and CUPB (ZLZX2020-01)

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