IOP Conference Series: Earth and Environmental Science

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IOP Conf. Series: Earth and Environmental Science **188** (2018) 012071 doi:10.1088/1755-1315/188/1/012071

Performance evaluation of water soluble diverter agent and its temporary plugging effect in refracturing

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Abstract. Refracturing is one of the important ways to restore well productivity and improve the ultimate recovery. Currently, the most effective way of refracturing is reorientation refracturing using diverter agent. In this paper, a water soluble diverter agent was synthesized by environmentally friendly non-toxic materials, the diverter agent particle size can be customized according to the fracture width, and it has good water solubility and can be water soluble completely after 4 hours of fracturing operation. Cores flow experiments show that the water soluble diverter agent plugging efficiency can reach more than 99% under over 40 MPa pressure, it has little harm effect on cores permeability, which satisfies the requirements of refracturing. The water soluble diverter agent was applied in filed for one well, the refracturing pressure increased 5 MPa after adding the water soluble diverter agent, which showed a good temporary plugging effect. The daily production after refracturing increased 1.98t, water cut decreased 10%. The results show that this refracturing mode is able to restore well productivity and decrease water cut.

1. Introduction

Stimulating and stabilizing oil production while enhancing the oil recovery has evolved into a crucial issue restricting the oilfield development, as most of oilfields in China have stepped into the mid-late development stage. The reservoir simulation technology plays an ever-increasing role in stabilizing production and enhancing oil recovery. Refracturing is one of the important method to tap the potential of old wells [1,2]. Under certain circumstances, the well productivity can be restored, and even increased, with the help of such treatments, which leads to enhanced oil recovery, and increased and stabilized production.

Geologic evaluation and fracture evaluation prior to the refracturing are of great importance for treatment effectiveness. The refracturing method can be divided into three types [2,3]. The first one is to further extend previous artificial fractures. After understanding the reason for the initial fracturing failure, success can be expected for a large-scale refracturing treatment, in cases that it is indeed the fracture itself that causes the treatment failure. The second one is to create new fractures using temporary plugging agents in the process of refracturing. The pore pressure falls later during the production after initial fracturing, which leads to reduction in the difference between the maximum principal stress and minimum one (or even the situation where the two previously minimum one exceeds the initially maximum one) [4]. In such cases, temporary plugging agents to increase the net pressure inside the previous fracture, secondary fractures to extend along the vertical direction of initial fractures and reach the untapped reservoir volume or regions with smaller pressure drop. The third type is a combination of two methods above. There are two stages for this method. In the first stage, large scale hydraulic fracturing is used to extend the initial fractures and improve their length and conductivity, while in the second one, temporary plugging agents are used for fracturing diversion to increased fracture net pressure.

So far, the most effective diversion technique fracturing is the use of temporary plugging agents to veer the fracture propagation. By adding of diverting materials with varied grain sizes into the fracturing fluid, tight blockage can be formed inside the perforation tunnel or hydraulic fracture and thus the net pressure inside the fracture climbs up. In order to raise up the strength of the blocking barrier, the diverting materials are required to be a mixture of particles with different sizes (larger particles first form the pack, and then smaller particles occupy the void space among larger ones). Extensive studies on temporary plugging materials have been carried out all over the world [5]. Halliburton uses biodegradable particles as the diverting agent in refracturing treatment [6,7].

This paper proposed a water-soluble temporary plugging agent composed of biodegradable materials, which is proved to be safe for both the environment and human body. The agent was tested in the laboratory. It can be processed into any diameter to meet the plugging requirement on particle sizes raised up by fractures and perforation tunnels with different sizes. The agent presented good water solubility, favorable compatibility with conventional fracture fluids, high plugging efficiency, high pressure-bearing capacity and low residual damage to core samples. The field test in one well indicated that the temporary plugging performance was great and excellent results of refracturing were seen.

2. Laboratory performance evaluation

2.1. Particle size selecting

The particle size of temporary plugging agents can be customized to the size of the perforation and fracture that is supposed to be plugged. According to our investigation and previous field test results, the agent combines more than three types of particles (components) can generally achieve a good plugging result, and meanwhile larger grain size differences are appreciated. The mixture of two types of particles (the ratio of them is 7:3), with each diameter no more than 5mm, was finally employed, for the sake of operation risks（table 1）.

Table 1. Relationship between temporary plugging agent diameter and fracture width.

Fracture Width (mm)	Temporary Plugging Agent Diameter	Proportion
0.5	40-mesh (0.43 mm)	0.86
1.0	20-mesh (0.85 mm)	0.85
2.0	10-mesh (2.00 mm)	1
3.0	8-mesh (2.36 mm)	0.77
4.0	6-mesh (3.35 mm)	0.84
5.0	4-mesh (4.75 mm)	0.95

2.2. Solubility evaluation

The determination of whether the agent can degrade and the degree of the damage to the fracture and proppant pack after refracturing is an important part of the evaluation of the temporary plugging agent.

- Experiment

In the experiment, 30% temporary plugging agent was added into the clean water, 0.1% guar gum fracturing fluid and 2% KCl surfactant-based fracturing fluid at 80°C and 0.1 MPa. Then the mixture was kept in the 80°C thermostatic water bath to observe the change of the water-soluble temporary agent with time passing by.

- Results

After 60 minutes of water bathing, the water-soluble controllable temporary plugging agent in the three fluid systems all dissolved, with extremely slight residual particles. The solutions were relatively viscous, presenting notable resistance to stirring. Moreover, liquids were seen to stick to the glass rod after stirring. After 240 minutes, the plugging agent dissolved completely, with no particle left, but the solutions maintained certain viscosity.

The water-soluble temporary plugging agent shows good water solubility. It can return to the surface together with the flowback fluid after fracturing, causing no damage to the fracture and proppant bed and conforming to the requirement of non-damage fracturing treatment. Meanwhile, the water-dissolution-based degradation time of the water-soluble temporary agent also suggests that the post-fracturing shut-in duration should generally last no less than four hours so as to achieve complete dissolution of the agent.

2.3. Temporary plugging performance

The sealing effect and pressure-bearing capacity of plugging agents are key parameters to evaluate its diverting performance.

- Experiment

The sealing effect of temporary plugging agents can be determined by measuring the core permeability before and after plugging operation. Another factor, namely the pressure-bearing capacity, can be assessed through the breakthrough pressure of the filter cake formed by the controllable temporary plugging agent pack with a specific thickness on the core end face under the reservoir temperature.

- Results

In the test, the artificial core sample was used, and its permeability under the reservoir temperature, tested using the standard salt brine. The permeability was initially 4.14×10^{-3} μm^2（figure 1）.

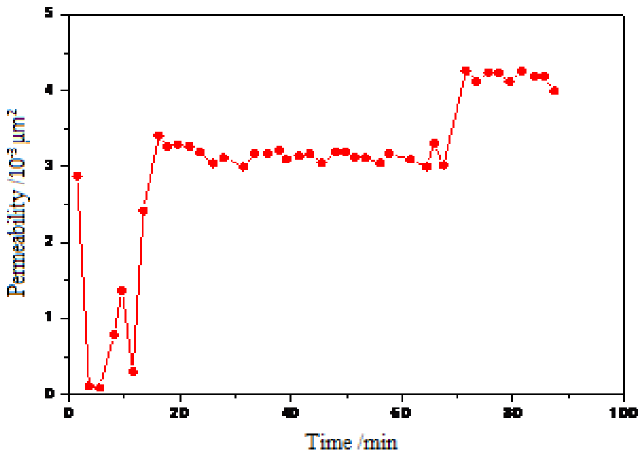

Figure 1. Liquid-based permeability of the artificial core sample.

At the room temperature, the controllable temporary plugging agent with a thickness of one centimeter was placed into a steel holder, and then the assembly was heated up to 80°C. The standard salt brine was injected into the holder at an constant rate of 10 mL/min, during which the pressure variation was recorded（figure 2）.

Comparison of the permeability before and after plugging shows that the core permeability reduces from 4.14×10^{-3} μm^2 to 0.0048×10^{-3} μm^2. The permeability drops by 99.88%, which indicates remarkable blockage.

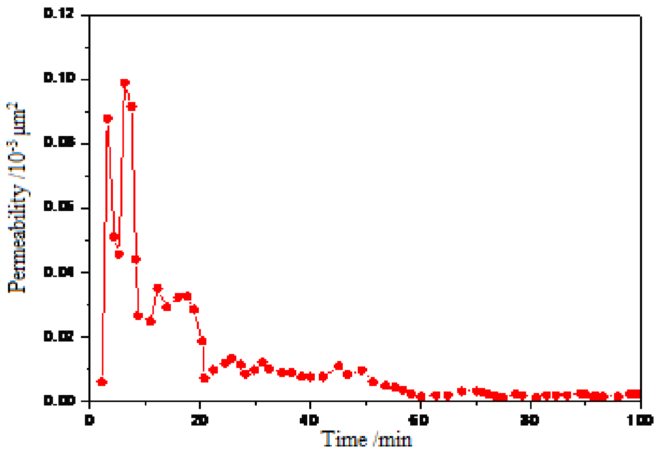

Figure 2. Permeability after sealing of temporary plugging agent (80°C).

The filtration rate of fluids significantly falls and the filtration volume growth slows down, as the injection pressure stabilizes at 40 MPa pressure（figure 3）. During 40 minutes of the experiment, the filtration rate is basically constant. This demonstrates that the water-soluble controllable temporary plugging agent with one-cm thickness can sustain 40 MPa at 80°C.

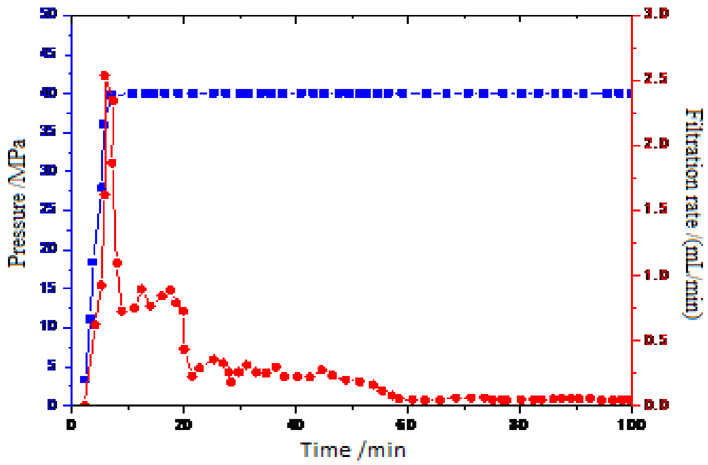

Figure 3. Displacement pressure and filtration rate after plugging vs. time.

Figure 4. The core sample plugged by water soluble temporary plugging agents.

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No apparent invasion of the water-soluble controllable temporary plugging agent system was found in the core section exposed after the core sample was cut and split（figure 4）. This suggests that the water-soluble temporary plugging agent is completely degraded.

3. Field test: temporary plugging and fracture diverting performance

3.1. Construction optimization: refracturing with temporary plugging-based diversion

The candidate well is located at the Changqing oilfield the Chang 6_2^1 reservoir. The perforated intervals include 1954.0 m - 1958.0 m and 1965.0 m - 1968.0 m. The well was put into production after fracturing September 1998 and the production of oil is 25.5t/d. The cumulative oil production for the well reached 28647 t by September 2015. In 2006, 2009 and 2012 respectively, acidizing was implemented in the well, and all treatments achieved good stimulation results. But in 2012, the effect-sustainable period for stimulation operation shortened significantly after acidizing involving temporary plugging. The overall water cut for the well increased gradually. The liquid production and oil production were 3.65 m^3/d and 0.60t/d respectively. Water cut increased to 80.5%. The analysis showed that the blockage may occur deep in the formation and thus conventional acid-assisted blockage removal treatments would be less effective. The cumulative water injection of the corresponding injection well amounted to 171091 m^3, and the injection profile, tested in April 2015, showed an apparent peak-shaped profile pattern. The bottom pressure data of the offset production well was 15.3 MPa, indicating that the formation energy was abundant.

Since the reservoir energy is sufficient, and previous acidization-based blockage removal are all seen with good results, it can be concluded that along the direction of the previous fracture is there still remaining oil. Moreover, in order to reduce the water cut and improve the producing degree of the remaining oil distributed along the direction perpendicular to the fracture plane, it was decided to adopt the refracturing approach in which the further extension of the initial fracture and the initiation of new fractures using temporary plugging-based diverting technique were integrated.

The design of the operation included 5 stages. The fluids in the first two stages were used to further extend and prop initial fractures. The scale of the stimulation job in these two stages was generally larger than the initial fracturing job for the extension of previous fractures and improvement of conductivity. Fluids of Stage 3 displaced proppants contained in the former slugs into the reservoir and meanwhile temporarily blocked fractures and perforation tunnels with added wate-soluble temporary plugging agents. Accordingly, the propagation of new fractures initiated afterwards was forced to deflect from (or even be orthogonal to) the initial fracture orientation. The injection procedures are as follow（table 2）:

Table 2. The refracturing procedure involving expanding initial fractures and creating new fractures using temporary plugging and diverting.

	Stages	Fluid Type	Pumping Rate (m^3/min)	Liquid Volume (m^3)	Proppant Amount (t)
1	Preflush	Base fluid + low-concentration surfactant solution	2.0	25	/
2	Sand-laden fluid	Crosslinked guar	2.0	100	40
3	Displacement Fluid + preflush	Base fluid + Water-soluble temporary plugging agent	2.0	20	/
4	Sand-laden Fluid	Crosslinked guar	2.0	50	20
5	Displacement fluid	Base fluid + low-concentration surfactant solution	2.0	6	/

3.2. Temporary plugging and diverting performance

The injection rate in the refracturing treatment was 2 m^3/min and the operation pressure (tubing) ranged from 17.82 MPa to 35.2MPa. The total fluid and proppant used for the frac job were 201.7 m^3 and 60 t, respectively（figure 5）. The operation pressure increased by 5 MPa after adding diverting agents into the fracturing fluid, and the temporary plugging effect was notable. The net pressure in fractures also rose up by 5 MPa, if not considering the friction resistance variation caused by the alteration of fracturing fluids. This increased net pressure led to good fracture propagation diverting effect, and fulfilled the operation expectation.

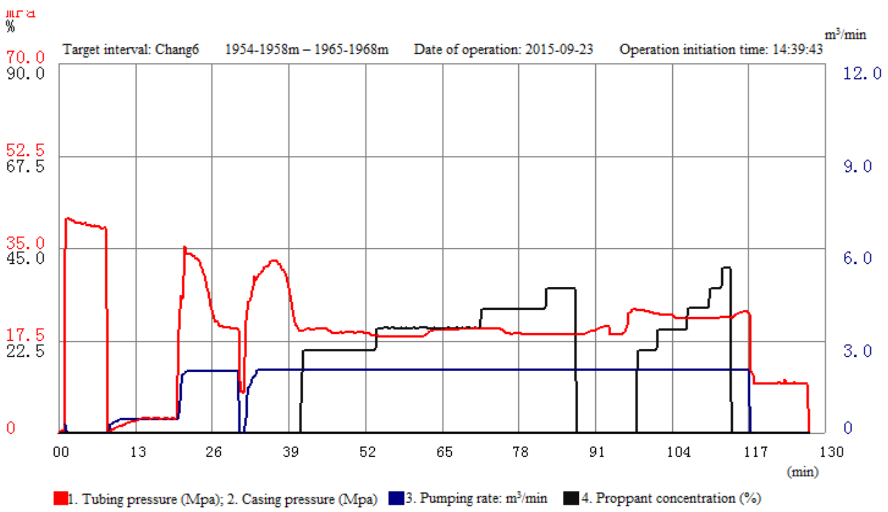

Figure 5. Field construction data during the refracturing process.

3.3. Stimulation result of the refracturing job

The well started to flow back after 4-hour shut-in. The flowback fluid had viscosity of 3 mPa•s, which proved that the gel breaking of the fracturing fluid and the water solubility f the temporary plugging agents were good. The reduced viscosity favored the flow back, and the damage induced by residual gel was limited. Before refracturing, the daily liquid production was 3.65 m^3/d; daily oil production, 0.60 t/d; water cut, 80.5%. However, after stimulation, the daily liquid production grew to 9.66m^3/d, the daily oil production increased by 1.98 t/d to 2.58t/d, and the water cut dropped to 68%（figure 6）. The production capacity of the well was restored, and the goal of decreasing the water cut was realized.

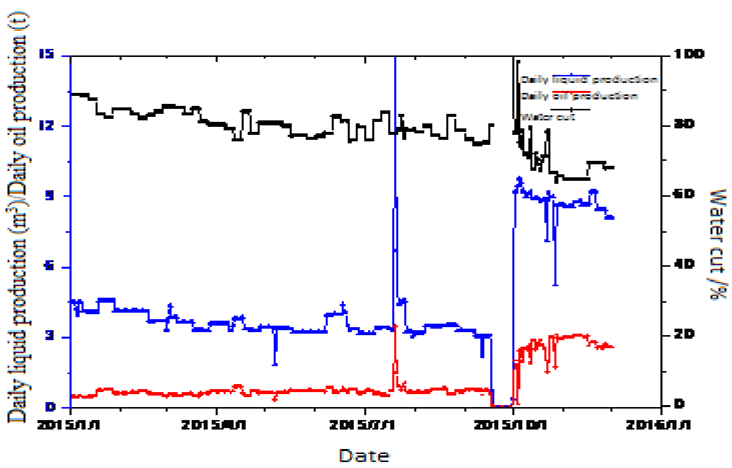

Figure 6. Production data before and after the refracturing treatment.

4. Conclusions

This paper synthesized a type of water-soluble temporary plugging agent using the biodegradable material, polymer, swelling agent and curing agent, which is proved to be safe for both the environment and human body.

The size of the temporary plugging agent can be customized, according to the fracture width. It has good water solubility and causes only slight damage to the reservoir after dissolution. The core plugging ratio is above 99% and pressure-bearing capacity is greater than 40 MPa.

The field test in a candidate well demonstrated that the tubing pressure after injecting diverting agents increased by 5 MPa and this led to good temporary plugging and diverting effects. The oil production increased by 1.98 t/d, and the water cut dropped by 10%, which indicated that the refracturing treatment have recovered well productivity and reduced the water cut.

Acknowledgments

The paper is supported by the National Science and Technology Major Projects of China (NO. 2017ZX05070) and (NO. 2016ZX05023).

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