The Research and Application of the Integrated Technology of Layered Water Injection and Profile Control

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Abstract: layered water injection and profile control are the leading technology to reduce the contradiction between layers and realize effective water injection and improve the development effect. With a water distributor it can realize that the integration completion of layered water injection and profile control. However, there are some risks with a small distributor channel, such as the large shear of the profile control agent, the blockage of bulk particles, and the tubing deposition of the returned profile control agent, which affect the effect of the profile control and water injection. Aiming at the existing technical problems, we deduced the mathematical model of the key tool profile control channel affecting the profile control agent apparent viscosity, developed a special profile control tool and switch matching with the injection process measurement and finally have formed anti-spit, low-shear integrated technology of layered water injection and profile control. A total of 9 wells were implemented, and the construction success rate was 100%. After profile control, the water injection starting pressure increased by an average of 3.4mpa, and the water content of the beneficial well was reduced by an average of 6%. Field application shows that the integrated technology of layered water injection and profile control can solve the problem of high viscosity loss rate and easy to return of the profile control agent, realize the safe and effective integration operation of layered water injection and profile control.

1. Introduction

86% of the reserves in dagang oilfield belong to artificial water flooding. The water flooding situation in the block is unbalanced, the interlayer contradiction is prominent, the water flooding layer in the vertical direction plunges, the water flooding efficiency is low, the ineffective circulation is serious, the production degree of thin and poor oil layers is low, and the water flooding effect is poor. In order to control the water injection rate of high permeability reservoirs, increase the water injection rate of low permeability reservoirs with poor water absorption, start non-water absorption reservoirs and improve the production degree of reservoirs. Separate injection and profile control are determined as the leading technologies for dagang oilfield to improve development effect and realize effective water injection.

58% of profile control wells in the oilfield use bridge eccentric water distributor or bridge concentric water distributor separate injection string for separate injection profile control, and the water distributor profile control passage (Φ20mm) is narrow. Profile control technologies such as organic gel+bulk swelling particles (5-30mm after swelling) are easy to cause shearing of profile control agent and blocking of channels by bulk swelling particles. Moreover, profile control agent is easy to vomit after profile control and deposit in “pockets” in the pipe string, affecting profile control effect and subsequent separate injection, measurement and adjustment. In view of the existing technical problems, the integrated technology of anti-reflux and low-shear separate injection profile control is studied, and the special profile control tools and switches matching with separate injection process measurement and adjustment are developed. In addition, it has been applied in the field and realized safe and effective integrated operation of separate injection and profile control.

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2. Research on Integration Technology of Separate Injection and Profile Control

In view of the limitations of the existing separate injection profile control integration technology, the overall implementation plan for process technology research is formulated:

1) The profile control tool is connected above the water distributor in the separate injection string in advance, which does not affect the passing of tools such as testing and sealing inspection and the normal operation of testing and sealing inspection.

2) When profile control is carried out, the steel wire of the test car used for the switch of profile control tool can be sent into the profile control device working barrel of the section needing profile control. The profile control tool switch is set into the profile control tool to seal the oil pipe below the profile control interval and inject the profile control system. The profile control channel is opened to realize profile control operation in any single-layer section;

3) After profile control is completed, the profile control channel is automatically closed. The formation profile control system cannot be returned to the oil pipe, so the profile control tool switch is fished out with the throw-and-pull joint, the pipe string is not moved, and normal water injection is resumed.

2.1 Integrated Process String

A three-stage and three-section profile control integrated process pipe string is designed to realize layered water injection without moving the pipe string after profile control. Profile control tools connected with the first layer and the third layer can respectively carry out profile control operations on this layer, and packers anchored by bidirectional slips are adopted at the top to prevent string creep during profile control and separate injection operations. The minimum internal diameter of the pipe string is φ46mm, which does not affect the post-injection testing, adjustment and sealing, as shown in Figure 1.

Table 1 Technological Parameter

Applicable well depth(m)	Applicable well deviation(°)	Working pressure(MPa)	Working temperature(℃)
⩽ 3000	⩽30	35	130

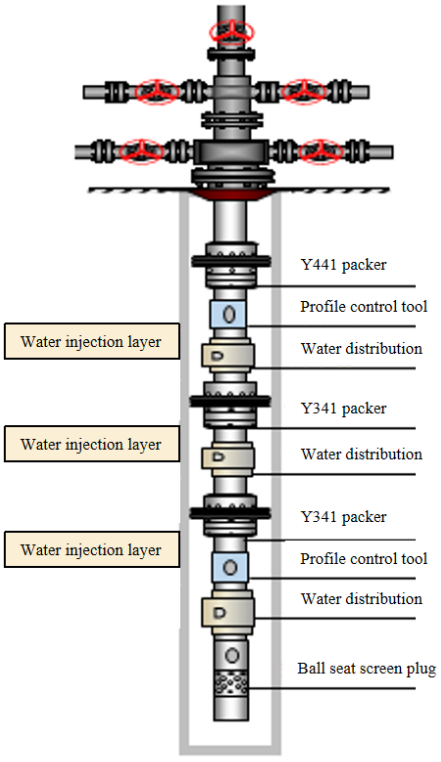

Fig.1 Separate Injection Profile Control Integrated Process Pipe String

2.2 Analysis of Integrated Process Technology

2.2.1 Running Profile Control Tools

When the pipe string is normally filled with water, the profile control tool is pre-installed above the water distributor in the water injection pipe string and installed in multiple stages as required. The design structure of profile control tool ensures its own closed state during water injection, does not affect normal water injection, does not affect the passage of tools such as testing and sealing inspection, the normal operation of testing and sealing inspection, and does not affect packer setting. The profile control tool is suitable for separate injection pipe strings composed of eccentric water distributors and concentric water distributors of any specification and model.

2.2.2 Opening Profile Control Tool Channel

When profile control is required, the steel wire of the test car for the profile control tool switch is sent to the lower part of the profile control tool working barrel of the required profile control interval and then slowly lifted up. The locking claw on the profile control tool switch is hung by the piston in the profile control working cylinder, the locking wheel rotates, the locking sleeve moves down under the action of the spring and the restriction on the lower supporting claw is released. The lower supporting claws are opened to both sides under the thrust of the opening spring, thus limiting the downward movement of the profile control tool switch. In addition, the linkage mechanism operates at the same time, so that the double positioning cam is opened under the action of the torsion spring, thus limiting the upward movement of the profile control tool switch, fixing the profile control tool switch in the profile control tool working barrel and sealing the profile control tool working barrel. At this time, the profile control tool switch has blocked the upper and lower sections of the profile control layer of the pipe string. Under the action of profile control fluid pressure, the ball valve compresses, and the profile control tool switch and the piston of the profile control working barrel move down together. The original return spring is compressed, and the piston moves down until the profile control fluid outlet is opened. At this time, the oil jacket is connected and the profile control fluid enters the formation, as shown in Figure 2.

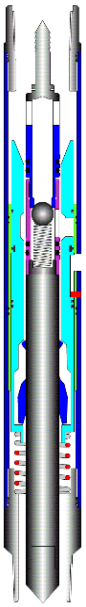

Fig.2 Switch in Profile Control Tool

2.2.3 Fishing out Profile Control Tool Switch

(3) Stop profile control operation, under the action of piston return spring, profile control tool switch moves up to the initial position, valve closes profile control fluid return channel. Run a special fishing tool, grab the fishing rod of the profile control tool switch, lift it up, the piston returns to the initial sealing position under the combined action of the lifting force and the return spring, the positioning ring on the piston is clamped into the positioning groove, and the profile

control liquid outlet is closed. The lifting force is increased, the profile control tool switch is cut to locate the shear nail, the displacement of the fishing rod releases the cam limiting device, the restriction of the piston on the upward movement of the profile control tool switch is relieved, and the profile control tool switch is successfully fished out. The working barrel of profile control tool is restored to the initial sealing position, and the water injection string is restored to the original state for normal injection distribution.

2.3 Technical Characteristics

(1) Avoid that deposition of profile control liquid, the profile control tool closes the pipe column below the profile control interval when work, realizes single-layer profile control of any interval of the pipe column, and avoids the deposition of profile control liquid in the pipe column;

(2) The quality of profile control is improved, the injection channel of profile control agent by special profile control tools is large, the viscosity loss of organic gel+bulk swelling particle profile control agent after entering the formation is small, the profile control channel is not easy to block, and the quality of profile control operation is improved;

(3) Prevent profile control agent from regurgitating. After profile control operation is stopped, profile control channel is automatically closed to prevent formation profile control agent from regurgitating.

(4) The invention has strong applicability, can be applied to the existing separate injection process, and does not affect the later test requirements.

3. Research on Key Tools for Integration of Separate Injection and Profile Control

3.1 Profile Control Tool

The flow process of profile control system at the outlet of profile control tool is equivalent to a flow process of varying cross section, and the flow of fluid at the outlet is assumed to be unitary, isothermal and incompressible, ignoring gravity. The flow process of profile control system out of the outlet of profile control channel is shown in Figure 3.

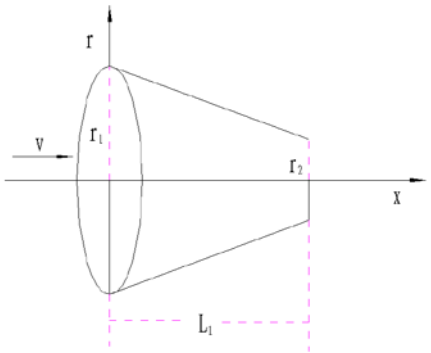

Fig.3 Flow Schematic of Profile Control System in Outlet Channel of Profile Control Tool

The profile control system is set to have a radius r_c at any section perpendicular to the x axis in the outlet flow phase, There are

$$r_c = -\frac{r_1 - r_2}{L_1} x + r_1 \qquad 0 \le x \le L_1$$

Using conservation of momentum to deduce the viscosity of polymer with radial upward profile in circular tube section is:

$$u_r = KR^{\frac{1+n}{n}} \left(\frac{3n+1}{n} \times \frac{Q}{\pi R^2}\right)^{n-1} r^{\frac{n-1}{n}}$$

In the formula: K is the consistency coefficient, Q is the flow rate, and R is the radius of the tube.

According to Newton's Leibniz formula, the average viscosity of profile control polymer solution on any cross section of an equal diameter circular tube is as follows:

$$\bar{u} = \frac{\int_0^R u_r dr}{R} = KR^2 \frac{n}{2n-1}\left(\frac{3n+1}{n} \times \frac{Q}{\pi R^2}\right)^{n-1}$$

If any section radius r_c is brought into $\bar{u}$, the apparent viscosity of any section of profile control polymer solution at the outlet flow stage is:

$$u_c = K \frac{n}{2n-1}\left(-\frac{r_1 - r_2}{L_1} x + r_1\right)^2 \times \left(\frac{3n+1}{n} \times \frac{Q}{\pi\left(-\frac{r_1 - r_2}{L_1} x + r_1\right)^2}\right)^{n-1}$$

Analysis of the apparent viscosity formula model for any section shows that: Under the condition of constant injection amount of profile control polymer, the smaller the outlet radius of profile control tool, the smaller the apparent viscosity of profile control polymer and the larger the decrease in apparent viscosity.

In order to reduce the shear of profile control polymer, increase the viscosity retention rate of profile control system and improve the profile control effect, considering the design size limitation and processing requirements of profile control tools, the maximum exit channel of profile control tools is designed to be $\varnothing 35mm$. At the same time, in order to verify the performance impact of profile control system after profile control of newly designed profile control channel and original profile control outlet channel, the gel forming strength comparison test of profile control system with 5m3/h injection volume before and after design was simulated on the ground. The test results prove that the newly designed profile control channel size can reduce the shear of profile control system and improve its viscosity retention rate, as shown in Table 2.

Table 2 Test Data of Profile Control for Different Channel Sizes

Profile control system	Channel size,mm	Viscosity,cp	Viscosity retention rate,%	Gelation strength,cp
Stock solution		162	/	Gelling, 18800
5m3/h stock solution after passing through water nozzle	φ20	135	83.3	Gelling,11200
5m3/ stock solution after passing through water nozzle	φ35	152	93.8	Gelling,17800

The low shear profile control tool designed and developed is matched with the testing and adjustment of separate injection process, and consists of upper and lower joints, outer sleeve, inner sleeve, guide body, return spring and other components, mainly constituting piston mechanism and return mechanism, as shown in Figure 4. The opening pressure of profile control channel is designed to be 2MPa, and the inner sleeve and piston are provided with positioning grooves and positioning rings. After normal water injection and profile control are completed, the positioning grooves and positioning rings fix the piston in a sealed position to ensure that the profile control device is in a sealed state.

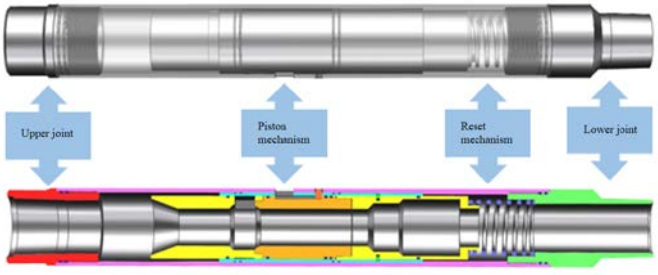

Fig.4 Profile Control Tool

3.2 Profile Control Tool Switch

The profile control tool switch consists of a fishing head, a core body, a positioning cam, a ball valve, a valve seat, a spring, a lower supporting clamping jaw, a locking sleeve, a locking wheel, a locking jaw, a lower guide body, a shearing nail and a plurality of torsion springs from top to bottom. It mainly consists of anti-regurgitation, upward limit and downward limit mechanisms, as shown in Figure 5. The anti-regurgitation function is realized through the cooperation of the ball, ball valve, ball seat and spring switch. When the profile control pressure is higher than the formation pressure, the backflow prevention channel is opened and the profile control system is injected into the formation. When the local layer pressure is high, the backflow prevention channel is closed and the profile control system cannot enter the oil pipe.

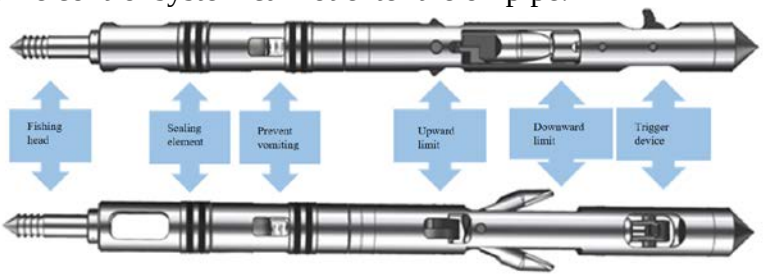

Fig.5 Profile Control Switch Tool

Use shear pin to control profile control switch tool delivery. The delivered shear pin force is designed to be 100KG, and the unsealed shear pin force is designed to be 200KG when fishing. The shear pin diameter is designed according to the shear strength condition:

$$d \le 2\sqrt{\frac{Q}{n\pi\tau_b}}$$

Where: d is the diameter of shear pin; Q is the total shear force when the pin is sheared. n is the number of pins; τ_b is the shear strength of the pin.

4. Field Application

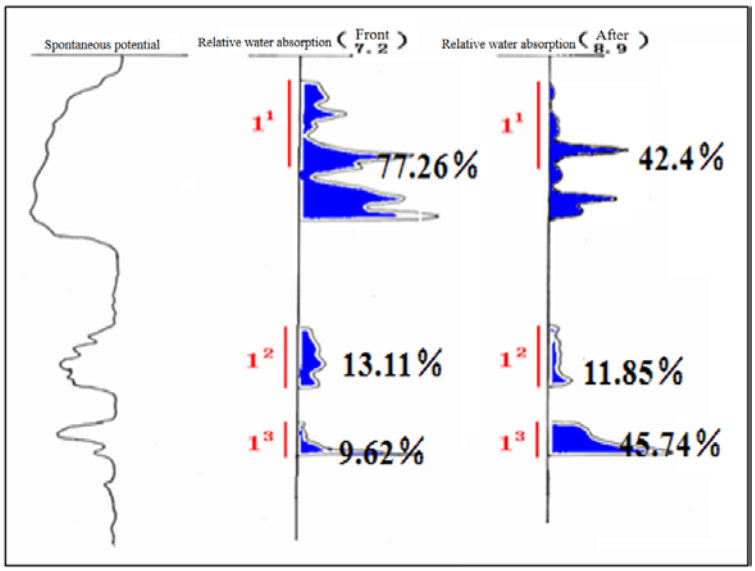

Fig.6 Comparison of Water Absorption Profiles of Hole 1016 Before and after Application of Split Injection Profile Control Integration Technology

At present, the integrated technology of separate injection and profile control has been applied to 9 wells in Dagang Oilfield, with a success rate of 100%, ensuring the smooth implementation of

separate injection and profile control. The maximum well depth applied on site is 3087.9m, the maximum well deviation is 18, the start-up pressure of water injection after profile control increases by 3.4MPa on average, and the improvement rate of water absorption profile reaches 100%, as shown in Figure 6. Water cut of beneficiary wells is reduced by 6% on average, of which hole 1016 corresponds to hole 1050-1 of well group, hole inspection 1 increases oil by 7.8t/d, hole 1015-1 corresponds to hole 1094-1 of well group, hole 1017-1 and hole 1094 increases oil by 10.13 t/d.

5. Conclusion

1) The integrated technology of separate injection and profile control has been applied to 9 wells in Dagang Oilfield, with a success rate of 100% and significant improvement in water absorption profile. The field application of the new process shows that: The integrated technology of separate injection and profile control solves the problems of high viscosity loss rate and easy regurgitation of profile control system in the prior art, and realizes safe and effective separate injection and profile control integrated operation.

2) The profile control tool can run into the well with the bridge type eccentric water distributor or the bridge type concentric water distributor once, complete the operation integrally, and increase the applicability of the separate injection process and profile control process. At the same time, the compatibility of layered water injection measurement and adjustment with surface equipment during profile control operation facilitates the popularization and application of the new process.

3) The innovation of this new technology provides technical reference for other underground operations.

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