Study on the law of Ultrasonic Wave Plugging

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Abstract—In the Chang Yuan area of Daqing oilfield, the field test of ultrasonic oil layer removal is carried out in the oil layer with different physical properties, different dynamic conditions and different water quality conditions. We evaluated the overall effect of ultrasonic remove near wellbore plugging, the system of technology parameters and reservoir static parameters, the dynamic parameters and quality of production of ultrasonic lift effect of near wellbore blockage, and ultrasonic, chemical plugging effect comparison. The test results show that the field parameters, static parameters of the reservoir and the dynamic parameters of production all affect the effect of ultrasonic plugging. The total processing time is longer, the better; layer selection priority Portuguese group two and senior group; under the same conditions, priority maximum permeability and small coefficient of variation, a small number of small, high strength injection layers; reservoir pollution, ultrasonic plugging treatment sooner the better. The initial injection efficiency of the two ways of chemical agent and ultrasonic wave is close, and the effective period of the plugging well is longer than that of acidizing well. Under the condition that the production cost of oil field is more and more precise, ultrasonic plugging and unmoving string, short construction time and long effective period can be used as a conventional plug removal method in oilfield application.

1. Preface
After years of development, some reservoirs of the oil field have been damaged in different degree, and caused the rise of injection pressure of water injection well and the failure to meet the requirement of injection allocation, thereby reducing the feed flow capacity of the oil production well and affecting the development effect. The main causes of injection-well plugging are: first, the change in the salt solubility of the stratum for form inorganic scale due to the change of temperature and pressure; second, the damage caused by injection medium, such as the fluctuations of the quality of the injected water, the injection stimulation fluid, the workover fluid and so on; in addition, the pollution to immediate vicinity of wellbore caused by the formation of emulsion band due to the uneven preparation of the chemical flooding medium injected, mismatch between the molecular size and oil layer, etc. [1-4]. At present, the commonly used plugging removal methods include the acidizing plugging removal: hydrochloric acid, mud acid, compound acid and other plugging removal techniques; new plugging removal techniques include comprehensive plugging removal, thermochemical plugging removal, chlorine dioxide plugging removal. Most of these techniques are chemical plugging removal, and have certain requirements for the oil layer and down-hole string. The ultrasonic plugging removal technology is one of the physical plugging removal techniques, and its mechanism is mainly to remove the plugging of the immediate vicinity of wellbore in the oil layer through the physical interactions such as the mechanical oscillation, cavitation and thermal interaction of acoustic waves on oil layers and fluids in oil layers to remove the plugging of the immediate vicinity of wellbore in the oil layer.
2. Mechanism of Ultrasonic Plugging Removal Technology

Ultrasonic plugging removal of water injection well is mainly to covert the power pulse electric oscillation signal generated by the ground vehicles into ultrasonic wave at the bottom of the well and inject the ultrasonic into the oil layer through special transmission cables, use the ultrasonic wave to stimulate the oil layer to lead to the change in the physical property and flow state of the fluid in the oil layer, and improve the circulation condition and permeability of the oil layer at the bottom and the oil layer near the well, so as to achieve the effect of plugging removal, scale prevention and removal, and paraffin prevention. Ultrasound has the following effects:

2.1. Shock Oscillation Peeling Effect
When the strong ultrasonic waves emitted by the directional beam act on the oil layer, the crude oil liquid, oil reservoir rock and solid particles will vibrate with the ultrasonic wave. Because of the different natural frequency of each liquid, rock layer and solid particle, the vibration acceleration and amplitude produced also vary, resulting in the relative motion of the interface of two types of phase states.

2.2. Cavitation and Viscosity Reduction Effect
Under the action of strong sound field, the molecular structure of crude oil will periodically arrange and combine to generate a lot of small bubbles under the strong oscillation. During the annihilation of these small bubbles, there will be ultra-high temperature and high pressure inside. This kind of local high energy may lead to the breakage of molecular bond of crude oil, that is, producing the cracking reaction, which changes the physical property of crude oil fundamentally, thus reducing the viscosity of crude oil.

2.3. Paraffin (Scale) Prevention Effect
Under the action of strong sound field, paraffin (scale) becomes extremely very fine particles suspended in the crude oil before it condensed, which causes the long-chain molecule to have a cracking reaction and reduces its curing strength. As the absorption of ultrasonic wave by the crude oil leads the temperature to rise, the sound energy can be converted into heat energy in large quantity at the liquid-solid interface, and the local high temperature at the interface may even produce ionization effect, thus effectively preventing paraffin (scale).

2.4. Technical Advantages
Ultrasonic plugging well and oil layer belongs to physical oil recovery. It will not inject chemical oil displacement. The technical will not destroy the ground and produce secondary pollution and there is no damage to the casing. Which was conducive to continuous production and environmental protection; Normal injection well and oil well can be operated directly (no dynamic string operation is required), with simple construction technology, convenient operation and short working cycle. Vehicle type is usually adopted and can be reused. Traditional oilfield stimulation techniques, such as acoustic water injection and acoustic acidification. It can be combined to give better play to oil recovery efficiency and improve oil recovery rate. It has fast effect, low cost of equipment, long effective period of increasing production, high input-output ratio, good safety and reliability. High directivity, cluster emission, good process selectivity, and can handle any layer. With good controllability, a series of technical parameters, such as downhole power, sound field intensity and treatment time, can be adjusted according to the downhole oil reservoir condition, so as to achieve the optimal parameter design of ultrasonic treatment.

The technical is mainly applicable to: drilling, mud immersion time is long, causing serious pollution to oil Wells; Oil Wells with severely blocked reservoirs and sensitive to water and acid; Oil Wells that are close to the oil-water boundary and cannot be stimulated by fracturing or stimulation; Oil Wells with good reservoir physical property and large reservoir thickness but poor oil production capacity, heavy oil Wells and paraffin Wells; oil Wells whose permeability drops sharply due to salt scale, scale blockage or contamination by mechanical impurities; Water injection Wells with ineffective acidification, high pressure and poor water absorption capacity.
3. Effect of Ultrasonic Plugging Removal

The effects of ultrasonic plugging removal measures are analyzed from two aspects: First, how the injection situation changes before and after the statistics at the injection end, and how the injection pressure and actual injection volume changes; second, observe whether the liquid yield and oil yield of the unconnected wells change and whether the water injection stimulation affects the oil well from the production end.

3.1. Effect of Injection-Well Plugging Removal

From the water well, it can be seen that the injection pressure decreased by 0.3 Mpa compared at the initial stage compared with that before the measure, the daily injection increased by 18 cubic meters, the injection volume stimulated per meter of sandstone thickness increased by 2.75 cubic meters, with an average validity period of 165 days.

Table 1  Statistical Table of the Effect of Ultrasonic Plugging Removal in Sazhong Development Zone in 2017

| formation   | wells | injection pressure (MPa) | daily injection (m³) | Injection pressure (MPa) | daily injection (m³) | period of validity (d) |
|-------------|-------|--------------------------|----------------------|--------------------------|----------------------|------------------------|
| Saertu&Putaohua | 23    | 12.4                     | 10                   | 12.2                     | 34                   | 183                    |
| Gaotaizi     | 29    | 14                       | 7                    | 13.6                     | 21                   | 155                    |
| Total        | 52    | 13.3                     | 8                    | 13.3                     | 27                   | 165                    |

3.2. Effect of Connecting Unmeasured Oil Wells

There were 140 unmeasured oil wells connected to the measured water wells. The daily production of fluid and oil showed an upward trend one month after the successful plugging removal of the measured water wells, and the water content was relatively stable and the effect was good, which proves that the effectiveness of the plugging removal measures.

4. Laws of Plugging Removal Effects

After the analysis on the well implemented with ultrasonic plugging removal within a few years, the factors that influence the effect of ultrasonic plugging removal are analyzed from the aspects of production performance, small layer static conditions and construction parameters. The rules are summarized as follows through data analysis and research:

4.1. Law of Dynamic Production

In terms of dynamic production, the relationship between the effect of measures and the production factors was analyzed mainly from three factors of injection-production well spacing, under-injection duration, injection allocation intensity.

4.1.1. The Larger the Injection-Production Well Spacing, the Lower the Injection Simulation Efficiency

The average injection-production well spacing between each water well and the connected oil well is calculated. The injection-production well spacing is divided into 5 grades, from less than 175 to more than 275 meters. After the statistics of the injection stimulation efficiency of the measured wells in the interval of each well spacing, the relationship curve (Fig. 1) is made, which shows that with the increase in the injection-production well spacing, the injection stimulation efficiency shows a decreasing trend, from 2.52 to 1.58. The main reason is that the smaller the injection-production well spacing, the better the efficiency of oil wells, and the better injection and production is conducive to the injection stimulation of the water well.
4.1.2. The Longer the Under-injection Duration, the Lower the Injection Stimulation Efficiency

The time from the discovery of water well plugging to the implementation of measures is called under-injection duration, and the under-injection duration is divided into 5 grades, from less than 3 months to more than one year. After the statistics of the injection stimulation efficiency of measured water wells in each under-injection interval, the relationship curve (Fig. 2) is made, which shows that the injection stimulation efficiency decreases from 3.42 to 1.58 with the increase of under-injection duration. The main reason is that the shorter the injection time is, the less tightly the plug is combined to the rock wall in the pore, and the easier it is to fall off under the action of ultrasonic wave.

4.1.3. The Greater the Injection Allocation Intensity, the Higher Injection Stimulation Efficiency

After the statistics of the injection allocation intensity before each section of measures to the well, the intensity is divided into every interval, and then the relation curve with the injection stimulation efficiency is made, which shows that the injection allocation intensity before the measure is relatively correlated with the injection stimulation efficiency after the measure, and the injection stimulation has a better effect with the increase in the injection allocation intensity before the measure. (Fig. 3) The main reasons are as follows: the greater injection allocation intensity proves that the greater the water injection potential of the oil layer, that is, the oil layer is well developed, and the better the effect of measure.

Figure 1 Relationship Diagram for Injection Stimulation Efficiency and Injection-Production Well Spacing

Figure 2 Relationship Diagram for Injection Stimulation Efficiency and Under-injection Duration
4.2. Law of Small-Layer Static
The static condition mainly takes into account the maximum permeability and the coefficient of vibration, which reflect the development of the oil layer.

4.2.1. The Greater the Reservoir Permeability, the Higher the Injection Stimulation Efficiency
After the statistics of the relationship between the small-layer permeability and injection stimulation efficiency, a scatter plot is made, which shows that there is a positive correlation between them, and the greater the permeability, the better the effect of the measure (Fig. 4). The main reason is that the larger the permeability of the core, the larger the radius of the plugging particles, so the larger the pull force produced by the corresponding ultrasonic wave, the better the plugging removal effect [8]. At the same time, with the increase in the radius of the core hole, the adhesion force between the particles and the pore wall and between the particles decreases, so that the stress state of the particles is easily changed and the particles are easy to fall off; in addition, the larger the core hole, the less likely to form a secondary blockage when the particles are discharged with the liquid.

4.2.2. The Smaller the Coefficient of Variation, the Higher the Injection Stimulation Efficiency
The coefficient of variation between layers is mainly used to reflect the heterogeneity of intervals. The closer the value is to 1, the stronger the heterogeneity is, and vice versa. The coefficient of variation of each water injection interval and the injection stimulation effect of the intervals are calculated statically, and a scatter plot is made, which shows that they are negatively correlated to each other, that is, the greater the coefficient of variation, the worse the effect of injection stimulation. The reason is that the stronger the heterogeneity, the more difficult the water injection. The effect of injection stimulation reflected is not obvious although the oil layer plugging has been removed.
5. Comparison of the Effects of Ultrasonic Plugging Removal and Acidizing Plugging Removal

The injection stimulation effect of wells treated with acidizing plug removal and ultrasonic plugging removal method in the same block, in the same series of layers and in the same year are compared, as shown in Table 1. It can be seen that the efficiency of the two methods is similar, but in terms of effective period, the effective period of ultrasonic plugging removal is obviously longer than that of acidizing plugging removal. Therefore, in the selection of measures, ultrasonic plugging removal can be preferably selected for construction.

Table 2 Comparison of the Effects of Ultrasonic Plugging Removal and Acidizing Plugging Removal in Sazhong Development Zone in 2017

|       | injection stimulation efficiency(m³/m.d) | period of validity(d) |
|-------|----------------------------------------|-----------------------|
| acidizing | 2.76                                   | 97                    |
| ultrasonic | 2.75                                   | 165                   |

6. Conclusion

The following rules can be drawn by analyzing the factors influencing the effect of ultrasonic plugging removal effect in the Changyuan areas:

1. Among the dynamic factors related to the effect of injection stimulation, the injection-production well spacing, the under-injection duration are negatively related to the injection stimulation efficiency, that is, the larger the spacing and the longer the under-injection duration, the worse the effect; the injection-production well spacing, the under-injection duration are negatively related to the injection allocation intensity, that is, the spacing and the longer the under-injection duration, the better the effect.

2. Among the static factors, the effect of injection stimulation is positively correlated with the permeability, that is, the higher the permeability, the better the effect; and the effect of injection stimulation is negatively correlated with the coefficient of variation, that is, the smaller the coefficient of variation, the better the effect.

3. The effect of acidizing plugging removal is similar to that of ultrasonic plugging removal, but the effective period of ultrasonic plugging removal is obviously longer than that of acidizing plugging removal in the Changyuan areas.

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