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Enhancing Daily Oil Production in Bottom Water Sandstone Reservoirs Using Large Pump Lifting

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Abstract
Bottom water sandstone reservoirs are characterized by thick sand body, thin oil layer and strong water body, etc. The distribution of remaining oil is affected by the type of interlayer configuration and permeability pattern, and is mainly distributed in the interlayer blocking parts, inter-segment low-permeability segments, and low-permeability segments of the oil and water coexisting segments. Usually, mechanical card packer and water plugging measures are adopted to dig out the remaining oil, but the effect deteriorates after many rounds of water shutting, and the management difficulty increases; therefore, a large pump lifting field test is carried out for the oil wells with high water cut. The test results show that large pump lifting can effectively utilize the remaining oil in the low-permeability section and around the wells, and when the permeability is within the range of reasonable extreme difference, the thicker the oil formation and the shorter the high-permeability section, the better the effect of lifting to increase oil; the large pump lifting test has achieved good economic benefits, and it is expected to become an important means to increase crude oil production and control water production during the high water cut period in bottom water sandstone reservoirs.
Keywords: *Bottom water sandstone, Remaining oil distribution, Large pump lifting, Water cut, Oil recovery*

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I. Introduction

Bottom water sandstone reservoirs in SINOPEC's western T oilfield are characterized by thick sand body, thin oil layer and strong water body, with oil-water ratio of more than 100 and active bottom water, and are currently developed mainly by horizontal wells [1,2]. With the deepening of development, the water cut continues to rise, low production and low efficiency wells increase year by year, the comprehensive water cut is as high as 83.0%, the distribution of remaining oil is mainly affected by tectonics, entrapment, reservoir non-homogeneity, faults, horizontal well trajectory, etc., and the remaining oil is rich in the low-permeability section between the segments and the perimeter of the wells, and how to utilize the perimeter of the reservoir in the high water cut wells has become a major problem faced by the bottom-water sandstone reservoir development[3].Since 2014, more than 20 high water cut wells have been carried out to change the big pump lifting liquid field test, the effect is overall better, but the related mechanism and influencing factors are still unclear, therefore, this paper firstly briefly introduces the remaining oil distribution law of the bottom water reservoir, and then analyze the mechanism of the big pump lifting liquids to recovery the remaining oil of the bottom water reservoir, combined with the analysis of the effect of the big pump lifting liquids of bottom water sandstone reservoirs to increase the effect of the measures, and explore the effect of lifting liquids of bottom water sandstone reservoirs influencing factors analysis. It is expected to provide reference for the subsequent development of this reservoir and the development of other similar bottom water sandstone reservoirs.

II. Study on the mechanism of fluid lifting in bottom-water sandstone reservoirs

2.1 Water Flooding Patterns and Residual Oil Distribution Patterns

The bottom water sandstone reservoirs in T oilfield are currently developed mainly by horizontal wells, with an average well spacing of 300 m. The permeability gradient of the horizontal section is large, and the local interlayer is developed, and the water flooding pattern is affected by the interlayer and permeability pattern [4]. Based on the location of the horizontal section in relation to the mezzanine, the flooding pattern can be categorized as fully sheltered mezzanine, trajectory through mezzanine, horizontal well through mezzanine type, and semi-sheltered mezzanine.

Fully sheltered mezzanine type is located under the horizontal section, sheltering the horizontal section is more effective, due to the tectonic factors or by the sedimentary factors, the mezzanine tilt is easy to communicate with the bottom water and form a strong secondary side water drive, the pressure landing above the mezzanine is larger after the production, the secondary side water is good for sweeping the oil, the degree of washing is high, the water drive efficiency is high, and it is easy to form a uniform water flood. The residual oil under this condition is mainly distributed below the mezzanine, and the residual oil above the mezzanine is mainly located at the top of the horizontal section.

Trajectory through mezzanine type, i.e., drilling in the mezzanine, part of the horizontal well section in the mezzanine through a longer distance, the mezzanine on the well track to form an effective shield, the bottom water needs to bypass the mezzanine to form a secondary edge of the water to drive oil, the energy is low supply of liquid poor liquid depth, the performance of the edge of the water reservoir characteristics of the water, the production process of the water cut is low and stable, uniform flooding, the residual oil is mainly located in the lower part of the mezzanine.

Horizontal well through the mezzanine type, the trajectory intersects with the mezzanine and crosses two rhythmic sections, the top and bottom of the mezzanine show obviously different water drive characteristics, the bottom water drive under the mezzanine, due to the short well section, generally shows point water flood; above the mezzanine due to the low degree of interference in the well section, it may be shown as a non-driven or weak secondary side water drive, the production process of the bottom water energy is strong, the supply of liquid is sufficient, the fluid level is shallow, and the flooding pattern is a point water flood. The residual oil distribution of this type is as follows: due to tectonic or sedimentary reasons, the well track passes through the mezzanine, and the upper and lower parts of the mezzanine have different depositional rhythms, so it is easy to form the upper part of the mezzanine to block the residual oil, and the remaining oil potential of the well section under the mezzanine is small because of the strong bottom-water drive, and the remaining oil potential is larger because of the fewer well sections activated by the mezzanine blocking and the interference between the well sections above the mezzanine.

Semi-sheltered mezzanine, the horizontal well trajectory is located on top of the mezzanine, the mezzanine is semi-obscured, the water drive mode is changed by the influence of the mezzanine, forming bottom water drive plus secondary marginal water drive. The production process shows that the fluid supply is sufficient, and the uncovered part of the mezzanine is utilized first, and then the upper part of the mezzanine is utilized. The water flooding mode is manifested as step-by-step water flooding. Influenced by the entrapment, the water flooding mode in semi-shielding shows bottom water flooding plus secondary edge water flooding, and the well section above the entrapment is more disturbed by the wells, and the residual oil potential is larger; in full-shielding, the edge water advances and then washes the oil well, and the potential is smaller.

For the wells without effective entrapment under the horizontal section, mainly bottom water drive, the factors affecting the permeability are mainly considered because of the highest correlation between the production of liquid and permeability in the horizontal section [5]. The output of the horizontal section is not only affected by the main output of the high-permeability section, but also by the combination of permeability on the horizontal section: when the permeability grade difference is more than 4, the low-permeability section is difficult to be mobilized, and when there is a transitional permeability between the high-permeability section and the low-permeability section and the grade difference between the adjacent permeability is less than 4, the low-permeability section will be mobilized step by step under the influence of the adjacent permeability. According to its distribution mode and water flooding morphology is divided into four specific categories: two-segment, step, sawtooth, and homogeneous, and the rest of the morphology are its different combinations of forms. The average difference between hypertonic and hypotonic horizontal section of two-section combination is more than 4, initially hypertonic utilization, point flooding, hypotonic section is longer and more potential, after hypertonic water production, due to the oil-water viscosity ratio, inter-well interference is serious, and the residual oil is mainly distributed in the hypotonic section. Step distribution permeability horizontal section step-by-step activation, step-by-step water flooding mode, the water cut rise in the production process is shown as a step, with a certain period of water-free oil recovery and low water cut period, due to the extreme difference between each permeability section is less than 4, the potential of high and low permeability step-by-step activation later is small, the step corresponds to the step-by-step water flooding mode, when permeability according to the combination of 4:2:1, because of the small difference between adjacent permeability levels, the horizontal section step by step, the main potential of the remaining oil is small, and the main oil is mainly distributed among the low permeability sections due to the serious interference between wells. The main potential of the remaining oil is small, mainly for the low permeability section oil and water without section. Sawtooth type is a multi-segment water production process, with a grade difference of more than 4, which is a multi-segment water flooding mode, with long-term high water cut production after seeing water, and it is difficult to utilize the low-permeability wells, and the residual oil potential is larger. Homogeneous type, manifested in the mode of "seeing water in the middle section - advancing along the well - lifting up the two wings - flooding the whole well", but there are fewer homogeneous flooding wells, flooding uniformly, and the remaining oil potential of the well section is small.

2.2 Ideas for fluid lifting in bottom-water sandstone reservoirs

Due to the influence of the type of mezzanine configuration and permeability pattern, the remaining oil is mainly distributed in the sheltered part of the sandwich, the low-permeability section between segments, and the low-permeability section with oil and water. Usually, mechanical sealing and water plugging are used to dredge this part of residual oil. Mechanical sealing is mainly used for horizontal section mining at the early stage of well production, and the applicable conditions are limited; water plugging is the most commonly used means to solve the problem of high water cut in oil wells, and the effect of water plugging to increase oil is better at the early stage; however, with the increase in the number of rounds of water plugging and the formation of advantageous channels, the effect of water plugging becomes worse, and the wells are still high in water cut after plugging, and the management difficulty is increased. For wells with high water cut that are difficult to be solved by existing means, try to lift the liquid by large pumps and utilize the remaining oil in the low-permeability section and the periphery of the well.

For bottom water sandstone reservoirs, when the well production differential pressure is greater than the critical production differential pressure, the oil-water interface lifts uniformly, forming a stable water cone near the bottom of the well. With the increase of well production, the height of the water cone increases until it reaches a certain production rate, the bottom water enters into the well, there are two kinds of flow near the wellbore: one is the bottom water cone into the region, due to the oil-water flow rate ratio is large, the water-phase seepage resistance is small, and the oil-phase seepage resistance is large, and the water-phase flow is larger, the oil-phase flow is smaller; the other is the bottom water has not swept through the region, and the seepage depends on the distribution of the oil-water saturation in the oil formation, and the oil-phase seepage The oil phase seepage resistance increases, and usually increase the production differential pressure to overcome the seepage resistance, due to the high energy retention rate of bottom water sandstone reservoirs, it is difficult to change the formation pressure, so it is recommended to increase the production differential pressure by adjusting the bottom flow pressure of the wells, use the low-permeability section between the segments and the residual oil around the wells, and lift the fluids to reduce the effect of the bottom flow pressure of the wells is obvious, to enlarge the range of the bottom water, and to drive out the residual oil of un-sweeping areas.

III. Application of Large Pump Lifting Measures in Bottom Water Sandstone Reservoirs

On the basis of studying the water flooding mode and residual oil distribution in bottom water sandstone reservoirs, screening of high water cut wells in bottom water sandstone reservoirs in T oilfield, mainly for some wells with water cut above 90% to carry out the large pump lifting liquid mine test, the test has achieved better results, some wells have better effect of controlling water and increasing oil, take TK-A and TK-B wells as examples.

TK-A well is located in the middle of Triassic reservoir structure in N area of T oilfield, the thickness of oil layer is 16m, the height of water avoidance is 11.8m, the length of horizontal section is up to 411m, the control area is large, the control reserve of single well is 40.0×104t, and the degree of recovery is 23%, and the degree of recovery is low. The attempt to lift the production began in January 2014, and the fluid quantity was upgraded from 80t/d to 150t/d, and the cumulative discharge of fluid in the cumulative period of 2.82×10^4t, the water cut was gradually reduced from 97.0% to 45.4%, and the cumulative oil increase in the whole cycle was 1.41×10^4t, which achieved good economic benefits. It is analyzed that the horizontal section of the well has no interlayer shielding, belongs to permeability master control, permeability is sawtooth distribution, permeability grade difference is large, non-homogeneity is strong, the middle section of the horizontal section has 65m of poor oil and gas layer, the trajectory of the point B is near the top of the sand, the trajectory is high, the physical property is poor, and the potential of the residual oil in the middle section and point B is rich, the well has gone through four rounds of plugging in the early stage, the effect is getting worse, and it is difficult to use the residual oil in the middle section and the point B. In order to use this part of the residual oil, the well is lifted by a large pump to lift the oil. In order to utilize the remaining oil in the middle section and point B, the flow pressure at the bottom of the well was lowered by lifting the fluid with a large pump, and the production differential pressure increased by 1.2MPa after lifting the fluid, and the remaining oil in the low-permeability section and point B was utilized, with obvious effect of oil increase. The production dynamics of the well is shown in Figure 1.

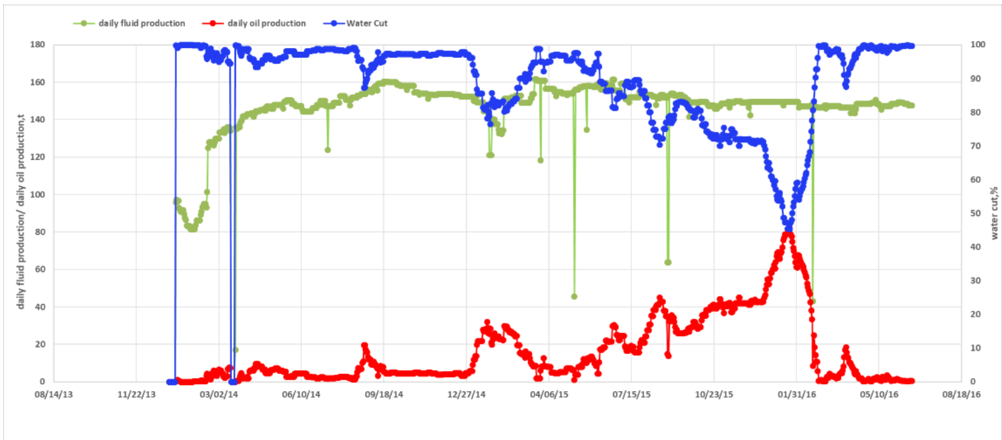

Figure 1 TK-A well production curve

TK-B well is located in the tectonic side of T-x block in T oilfield, the thickness of oil layer is 13.4m, the height of water avoidance is 10.6m, the length of horizontal section is 300m, the controlled reserve of single well is 193,000t, and the degree of recovery is only 2.9%.In June 2017, the liquid lifting production, the liquid volume was increased from 36.2t/d to 112.9t/d, and the water cut rate after liquid lifting was reduced from 99.9% to 96.0%, the daily oil production increased from 0.3t to 4.3t, and the cumulative oil increase is 131.5t up to now. The daily oil production increased from 0.3t to 4.3t, and the cumulative oil increase up to now is 131.5t. The area develops interlayer, the horizontal section penetrates through the interlayer, the heel end is located above the interlayer, relatively low permeability by the influence of the interlayer, the toe end is located below the interlayer, the point B is hypertonic, the bottom water breaks through along the hypertonicity resulting in water flooding, and the entire section of the well is currently combined and extracted. The remaining oil is mainly located in the low-permeability section of the toe end above the sandwich, and the differential pressure of the production increased by 1.5MPa after fluid lifting, and the remaining oil in the low-permeability section of the toe end has been utilized, and the water cut has decreased. Production dynamics of the well is shown in Figure 2.

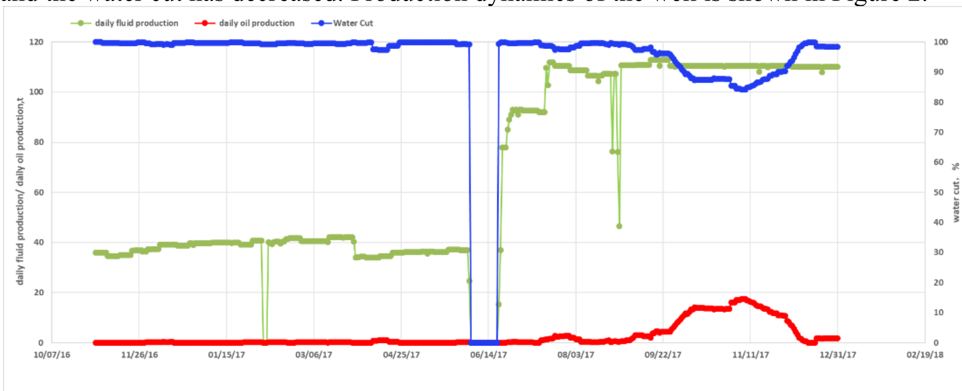

Figure 2 TK-B well production curve

IV. Study on the influencing factors of the effect of liquid lifting by large pumps

A detailed analysis of the current production situation of large pump lift wells in bottom water sandstone reservoirs of T oilfield is conducted, and it is analyzed that the large pump lift is mainly affected by a variety of factors, such as the thickness of the oil reservoir, interbedded layer, extreme difference in permeability, and the length of the well section.

4.1 Formation thickness

There is a close relationship between the oil production of wells in bottom water sandstone reservoirs and the thickness of the oil layer. Statistics on the oil increase of 9 wells with fluid lifting (Figure 3) found that the oil increase is positively correlated with the thickness of the oil layer, the thickness of the oil layer in bottom water reservoirs is large, the thickness of the water avoidance is large, and the residual oil recoverable reserves are relatively rich, and the fluid lifting can reduce the flow pressure at the bottom of the wells, increase the differential pressure of the production, enlarge the volume of the bottom water wave and volume, increase the range of the water drive application, and effectively utilize the residual oil around the wells.

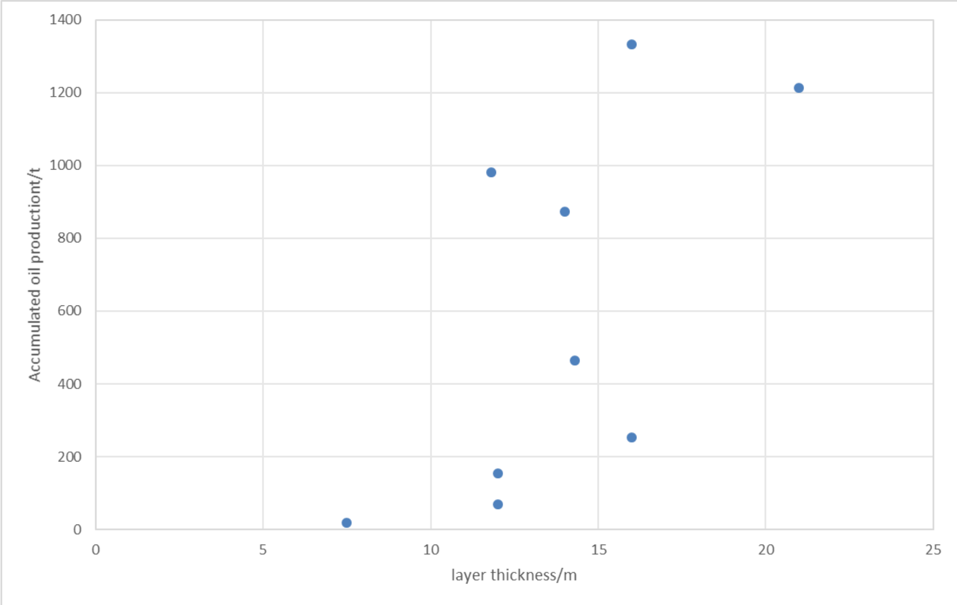

Figure 3 Relationship between oil reservoir thickness and oil increment

4.2 Mezzanine location

T oilfield bottom water sandstone reservoir development of three types of interlayer, muddy interlayer, physical interlayer, calcareous interlayer, with a certain spreading range of muddy interlayer can effectively inhibit the bottom water cone into the wave and the water cone morphology changes, the wave and the range of influence than the lack of interlayer is small, the bottom water bypassed the formation of the interlayer of secondary side of the water, the effect of the wash is better, the residual oil saturation is low, and a small range of impermeable interlayer formed at the bottom of the The remaining oil is less saturated, and a small area of impermeable interlayer forms at the bottom of the "roof oil", which is difficult to be driven out by enlarging the production differential pressure. Take TK-C well and TK-D well as an example, the trajectory of TK-C well passes through the entrapment, the heel end is located above the entrapment, and the remaining oil is mainly enriched in the toe end, but it is difficult to utilize the remaining oil near the entrapment at the toe end; the trajectory of TK-D well passes through the entrapment, and the entrapment is developed under the trajectory, and it fails to form a large-scale water cone after lifting the liquids, so the effect of oil increase is not obvious.

4.3 Permeability difference

Due to the strong non-homogeneity of the formation plane, there is a certain degree of non-homogeneity within the horizontal section, when the permeability difference is less than 4, the effect of the liquid lift to increase the oil is general, there is no obvious change in the water cut, the analysis is that the permeability difference is small, the effective differential pressure is basically the same, the liquid lift on the differential pressure is basically the same, the low-permeability layer section is not effectively utilized, the effect of the increase in oil is not obvious; When the permeability difference is between 4 and 12, after the liquid lift When the difference in permeability is between 4 and 12, the liquid production ratio of low-permeability layer section with low water cut increases, the oil production increases, and the remaining oil in the low-permeability section can be effectively utilized; when the difference in permeability is greater than 12, the low-permeability layer section with low permeability has a high utilization pressure, and the high-permeability layer section, i.e., the water section, is still being utilized, so there is no effect of the lifting of liquids.

4.4 Horizontal well length

For the permeability of the main control of the formation, the length of the relatively high permeability section in the production section (the main water section) determines the size of the water cone wave area after lifting the liquid, in the appropriate range of permeability extreme difference value, the relatively high permeability section is short, after lifting the liquid can be a large range of wave area, lifting the liquid effect is good, the TK-D high-permeability section accounted for the well section is longer, and the permeability grade difference is smaller, the effect of the lifting of the liquid is poor.

Therefore, the conditions for large pump lifting should be considered comprehensively in terms of reservoir thickness, interlayer, permeability and well section length, of which interlayer and permeability are the main controlling factors, and the wells with large reservoir thickness and permeability gradient in a reasonable range are preferred to carry out large pump.

V. Conclusions

1.T oilfield bottom water sandstone reservoirs, due to the influence of the type of sandwich (mezzanine) configuration and permeability pattern, the remaining oil is mainly distributed in the part of the sandwich blocking, inter-section low-permeability section and low-permeability section of the oil and water without section;
2. The effect of large pump lifting is mainly affected by the thickness of oil reservoir, interlayer, permeability and well section length;
3. Large pumping can effectively utilize the residual oil in the low-permeability section and the well perimeter, which can help to increase the production of bottom water sandstone reservoirs in the high water cut period.

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