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Density cutting volume fracturing technology for horizontal well in ultra-low permeability reservoir in Yuan284 area

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Abstract. The ultra-low permeability reservoir in Huaqing oilfield presents the characteristics of obvious non Darcy seepage, difficult matrix displacement, channeling of injected water along the waterflooding-induced fracture, and low production of single well in horizontal well development. Conventional water injection development is difficult to adapt to the current economic development. It is urgent to explore the effective development mode of horizontal well in ultra-low permeability reservoir, that is, to transform water-flooding development mode. Based on the mechanism of imbibition oil recovery, through indoor numerical simulation and field test, this paper innovatively puts forward large-scale volume fracturing of horizontal wells, and establishes a new development model of "makeup pressure tightness production" integrating "comprehensive energy supplement, old fracture plugging, synchronous transformation and volume fracturing" for the first time, which breaks through the traditional water drive characteristics and is successfully applied to yuan284 block of ultra-low permeability reservoir in Huaqing oilfield. Through the three-dimensional transformation of the reservoir, this model increases the complexity of fractures, realizes the transformation of seepage from linear flow to complex fracture network, establishes the development mode of imbibition displacement + differential pressure mass transfer, changes from well controlled reserves relying on water drive to fracture controlled reserves relying on seepage, and finally greatly improves the production and recovery of single wells. It is concluded that changing the water injection development mode provides new ideas and technical support for the development of horizontal wells in other similar ultra-low permeability reservoirs.

Keywords: Ultra low permeability reservoir; transforming water-flooding development mode; Horizontal well; Imbibition displacement; Closed well energy storage.

1. Introduction

Ultra low permeability reservoir has dense lithology, high oil saturation of core, poor connectivity of reservoir sand body, small overall control area of single sand body, and the configuration relationship of oil, water and pore roar determines the fluid fluidity, while the radius of main roar in ultra-low permeability reservoir is only 0.11μm2,the final oil displacement efficiency is 39.53%, resulting in poor seepage environment, and it is difficult to establish effective displacement pressure system in some reservoirs [1-4]. At the same time, due to the development of natural fractures in the reservoir, once the water injection pressure exceeds the opening pressure of natural fractures or formation fracture fracturing [5-6], the production wells in the main stress direction will be rapidly flooded, Therefore, there are common problems in the development of horizontal wells with low liquid and low production, or water breakthrough when water injection is effective. Huaqing oilfield has the advantages of large oil layer thickness, high reserve abundance, stable and continuous oil layers and large geological reserves controlled by single wells. In recent years, the volume fracturing technology of horizontal wells has been gradually popularized. The research and application of volume fracturing of horizontal wells has become the core technology of EOR in ultra-low permeability reservoirs of Huaqing oilfield [7-8]. Therefore, based on the mechanism of imbibition displacement oil production, the author studies the adaptability of changing water injection development mode in ultra-low permeability reservoir of Huaqing oilfield through the combination of numerical simulation and field development practice. The research results show that the transformation of water injection development mode of horizontal wells can greatly improve the production and recovery of single wells, and its results can form a new

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development mode that can be copied and popularized, solve the bottleneck problem of ultra-low permeability reservoir development and improve the development effect.

2. Transformation of water injection development mode and establishment of a new model

2.1 Mechanism of imbibition displacement oil recovery by changing water injection development mode

Change the water injection development mode and break the boundaries of oil and water wells for the first time. All wells adopt the development mode of volume fracturing quasi natural energy development and huff and puff + energy supplement between fractures through the displacement between the well and adjacent wells. Through the imbibition displacement, break through the characteristics of traditional water drive and realize the "Four Transformations". ① change from traditional water drive to huff and puff imbibition; ② From infilling adjustment to improving reservoir production; ③ The seepage flow changes from linear flow to complex fracture network; ④ By changing from fixed well type to changeable well type, a "recharge pressure stuffy production" technology integrating comprehensive energy supplement, old fracture plugging, synchronous transformation and volumetric fracturing (Fig. 1 and Fig. 2) is formed, which greatly improves the production of single well and stage cumulative oil production, and finally improves oil recovery.

The core of changing the water injection development mode is to carry out large-scale volume re pressure centered on the well, reduce the driving differential pressure required for oil and gas seepage to fractures in the matrix, improve the reserve production rate and realize fracture controlled recoverable reserves. According to the mechanism of imbibition displacement, the oil recovery rate of imbibition displacement after large-scale volume fracturing of horizontal wells can be expressed by non Darcy seepage theory formula,

$$\Delta q = \frac{K_a}{\mu}(\Delta P - \lambda \Delta L) \cdot V_a \cdot \beta \tag{1}$$

Where: Δq is the imbibition production rate within the scope of large-scale volume transformation of horizontal wells, m3/d; Ka is matrix permeability, 10-3μm2； μ is crude oil viscosity, mPa·s; λ is the starting pressure gradient, MPa/m; Δ L is the driving distance of fluid between matrix and fracture, m; Va is the reservoir volume, m3; β it refers to the degree of fracture cutting after the matrix is volume fractured.

According to formula (1), the imbibition displacement is mainly related to two factors: the imbibition displacement speed is in direct proportion to the scale of reservoir reconstruction, that is, the larger the number of fracturing sections, sand addition, displacement and liquid inflow of horizontal wells, the stronger the imbibition, the smaller the starting pressure gradient, and the faster the imbibition oil recovery speed; At the same time, it is positively correlated with the development degree of artificial fractures after reservoir reconstruction, that is, the more developed the three-dimensional fracture network near the well after large-scale reconstruction of horizontal wells, the greater the artificial fracture bandwidth, the stronger the imbibition, and the smaller the driving distance between the fluid and the fracture. Through the above analysis, the test of horizontal well changing water injection development mode in Yuan284 district also realizes technical optimization from these two aspects.

2.2 Establish a new oil production model of imbibition displacement + differential pressure mass transfer

According to the driving mechanism of matrix fracture network, a comprehensive characterization development mode of differential pressure mass transfer and imbibition

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displacement is established after large-scale volume fracturing of horizontal wells. The fracture network structure is the main controlling factor affecting matrix fracture mass transfer. The oil production rate after volume fracturing is the sum of imbibition displacement and differential pressure mass transfer, that is:

$$Q_w = \Delta q + q_w \tag{2}$$

$$q_w = C_f \frac{K_w A}{\mu}(p_f - p_m) \tag{3}$$

Where: Qw is the total mass transfer within the scope of large-scale volume transformation of horizontal well, m3/d;Δq is the imbibition production rate within the scope of large-scale volume transformation of horizontal wells,m3/d; qw is the differential pressure mass transfer and oil production rate, m3/d.

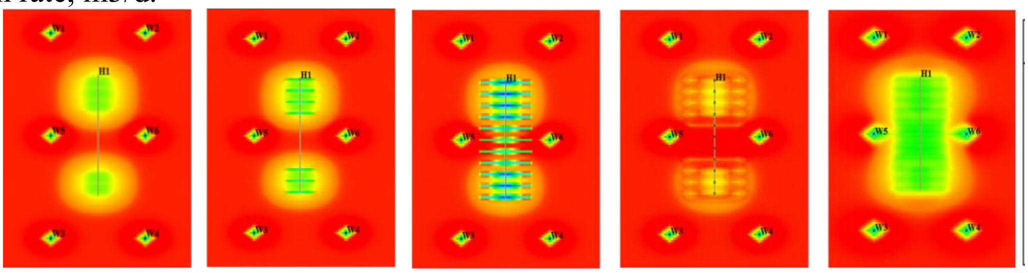
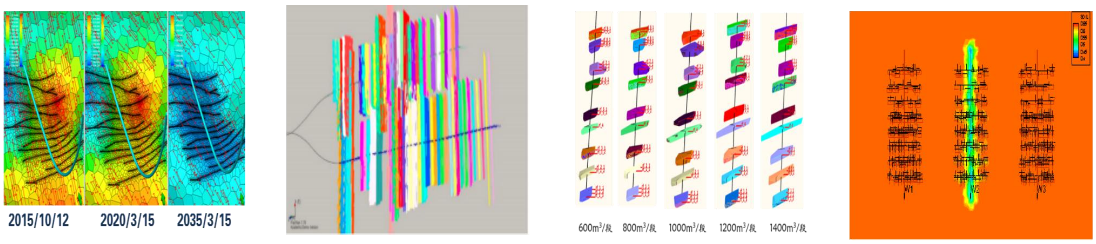


Figure1. Simulation of oil saturation field in five stages of large-scale volume fracturing of horizontal wells



(Energy supplement before compression) Change of orientation / magnitude of minimum principal stress in production

(Volume fracturing) Simulation diagram of crack shape after volume recompaction

(Increasing energy in pressure) Volume simulation diagram of transformation with different liquid entering the ground

(Pressure follow-up energy) Huff and puff + inter fracture displacement saturation change diagram

Figure2. Technical mode of "energy supplement before pressure, energy increase during pressure, capacity expansion after pressure and inter fracture displacement"

3. Field test effect

3.1 Block overview

The main development layer series in Yuan284 area of Huaqing oilfield is the Triassic Yanchang Chang6 oil layer group. The overall structural form is a slightly westward inclined monoclinal structure. The stratum occurrence is gentle, the stratum dip angle is less than 1 °, and the average slope is 2 ~ 3m / km. Due to differential compaction, nose uplifts in the axial direction of near East-West or northeast are developed, and there are structural highs and lows in some parts, The top structure of each small layer is inherited vertically.

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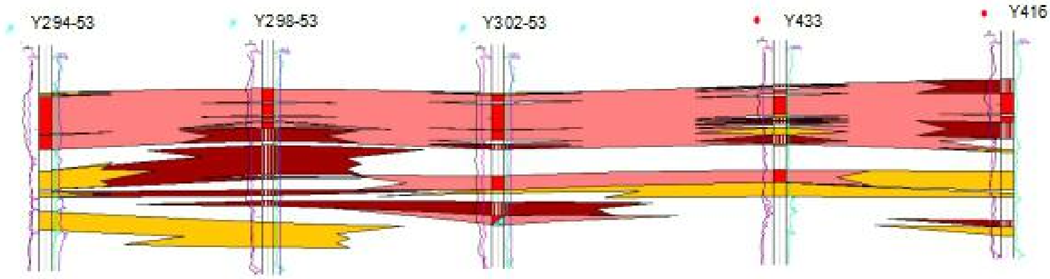

Figure3. Reservoir profile of well Y 294-53-Y 416 in Y 284 area

3.2 Application of new mode of changing water injection development mode

The proved oil-bearing area of yuan284 District of Huaqing oilfield in the study area is 223.8 square kilometers, the proved geological reserves are 141 million tons, the produced geological reserves are 101 million tons, the buried depth of the reservoir is 2100 meters, the thickness of the reservoir is 19.7m, and the permeability is 0.37md. In the process of water injection development in recent ten years, the oil production rate of the geological reserves is only 0.20%, and the recovery degree is only 2.33%, It is urgent to carry out the test of changing water injection development mode to improve the effect of volume fracturing measures in horizontal wells.

3.2.1 Pre pressure energy supplement parameters can quickly supplement formation energy

The formation pressure in Yuan284 area of Huaqing oilfield is low, 13.2Mpa. The volume of conventional horizontal wells decreases rapidly after fracturing. The test of changing the water injection development mode can quickly supplement the formation energy before fracturing, increase the fracture width through synchronous overall broadband fracturing, improve the vertical production degree of the reservoir, and synthesize the recovery degree and pressure level of the well group, After the numerical simulation analysis of oil production , it is concluded that the maximum utilization of reserves can be achieved when the formation maintenance level is 110-120% and the liquid inflow of a single well is 8000 ~ 10000m3.

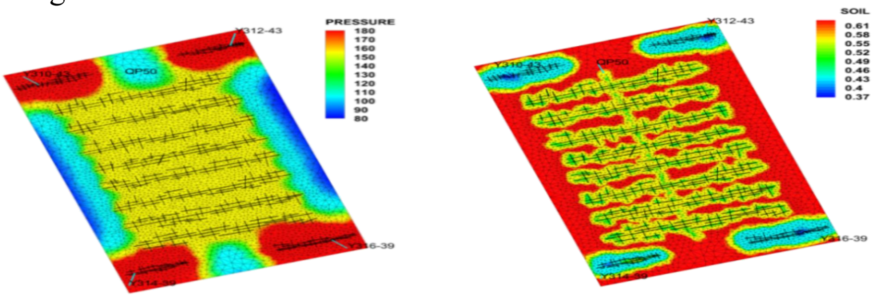

Figure4. Pressure field and saturation field after volume fracturing + water injection huff and puff

3.2.2 Changing water injection development mode and reservoir reconstruction mode

Yuan284 horizontal well area was built on a large scale in 2012, and the water injection development mode was changed. The average length of the horizontal section of the horizontal well in the test area is 800m. Take the test wells cp52-10, cp52-11 and cp52-12 in 2019 as an example, as shown in Table 1. The initial reconstruction adopts multi-stage and multi cluster fracturing, with an average number of 15 fracturing sections and a single section of sand addition of 27.5m^3, The sand ratio is 28.6%, the displacement is 3.0L/min, and the total liquid inflow is 2812.6m^3,In this test, the scale of reservoir reconstruction of horizontal wells is greatly increased, the average number of fracturing sections is 22, and the amount of sand added in a single section is 110.0m ^{3}, The sand ratio is 17.0%, the displacement is 8.0l/min, and the total liquid inflow is 41079.9m^3, Compared with the initial transformation scale, the transformation volume is increased by more than 15 times, and the average daily liquid production of three horizontal wells is 11.0m before the test ^{3}, The daily oil output is 8.9t, the water content is 19.4%, the dynamic liquid level is 1417m, and the average

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daily liquid output after the test is 44.7m³, The daily oil production is 40.9t, the water content is 8.5%, and the dynamic liquid level is 565m. After the test, the daily oil production level increases significantly.

Table1. Implementation scale and effect statistics of large-scale volume fracturing in horizontal wells

Well number	Initial transformation parameters					Parameters of this transformation					Daily oil increase/t	Cumulative Increase oil/t
	Number	Sand quantity /m³	Sand ratio/%	displacement /L/min	Total liquid volume into the ground /m³	Number	Sand quantity /m³	Sand ratio /%	displacement /L/min	Total liquid volume into the ground /m³		
CP52-10	16	31.3	24.4	3.0	3927.4	22	133.7	16.8	8.0	47475.1	8.5	4223.9
CP52-11	19	26.1	29.5	2.4	2849.5	23	69.5	17.4	8.0	38830.5	10.5	7331.5
CP52-12	11	25.0	31.9	3.0	1660.9	22	126.6	16.9	8.0	36934.3	15.5	9892.6

3.2.3 Post pressure capacity expansion increases reservoir imbibition displacement

According to Warren root model, the effect analysis of indoor core imbibition displacement experiment is carried out, as shown in Fig. 6. The results show that the imbibition front of injected water in the matrix continues to advance with the increase of well plugging time after volume fracturing. After 40 days of well plugging (Fig. 7 and Fig. 8), the invasion distance of injected water tends to be stable by 0.2m, that is, the invasion degree depends on imbibition is 33.3%, so as to determine the optimal well plugging time of 40-60d in the study area.

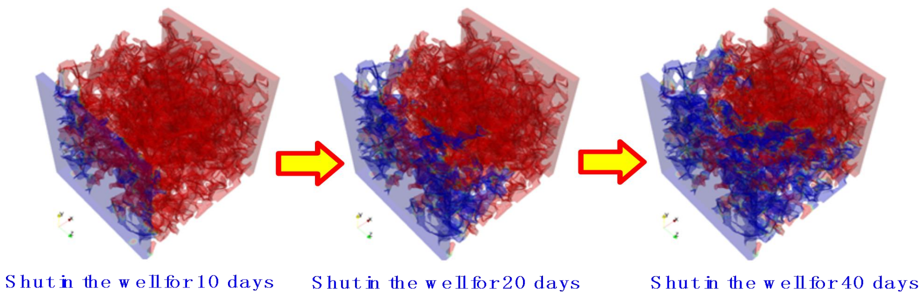
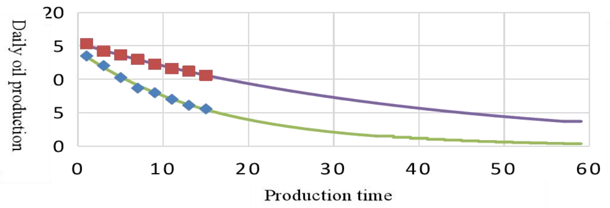


Figure6. Simulation of ground fluid invasion into matrix and oil-water infiltration and replacement



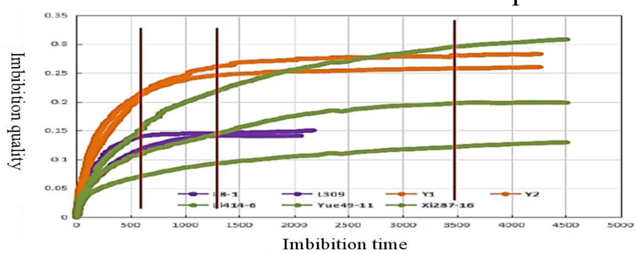


Figure7. Comparison curve of daily oil production after capacity expansion and without capacity expansion after horizontal well pressure Figure8. Variation law of infiltration with well plugging time

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3.3 Application effect

In 2017, the test of horizontal well changing water injection development mode was carried out in block yuan 284, and 8 large-scale volume fracturing were carried out, with an average number of fracturing sections of 11 and a sand adding amount of 680m ³, The displacement is 3.0l/min, and the liquid entering the ground in a single section is 711m ³, According to formula (1), by increasing the reconstruction scale, the volume fracturing effect of horizontal wells can be increased and the output of single wells can be improved. Therefore, the average number of fracturing sections of three horizontal wells is 22 and the sand addition is 3000m in 2019 ³, The displacement is 8.0l/min, and the liquid entering the ground in a single section is 1863m ³, From the comparison Figure, it can be seen that the transformation scale is positively correlated with the production. The production of wells implemented in 2019 has been greatly improved. The daily oil increase of horizontal wells was 11T in the initial stage of 2017 and 33T in 2018. When the liquid inflow of a single section increased to more than 1000m3, the decline was controlled at 10.6% in the six months after the measure. Up to now, the overall daily oil increase was 26.9t, and the cumulative oil increase was 3.4% × 104t, see Table 2 and figure 9 for details. The production is 15 times that of the surrounding horizontal wells. The oil recovery rate is increased from 0.20% to 1.15% before the test, and the predicted final recovery rate is increased from 5.3% to 12.3%. The oil recovery rate and single well production of the block are significantly improved.

Table2. Production situation of large-scale volume fracturing transformation of horizontal wells with transforming water-flooding development mode in Yuan284 area

number	Well number	Completion date	Production before measures			Current production			Cumulative oil increase/t
			Daily liquid/ m^3	Daily oil production /t	containing water%	Daily liquid/ m^3	Daily oil production /t	containing water %	
1	QP49	2017/5/19	2.4	1.2	49.1	4.3	3.0	30.2	1504
2	QP50	2017/6/25	2.4	0.8	66.8	4.8	3.4	31.1	2024
3	QP19	2017/8/4	1.9	1.4	25.9	4.5	3.2	29.8	1683
4	QP20	2017/10/18	2.9	2.6	9.7	11.2	6.8	40.8	1415
5	QP48	2017/11/14	3.1	2.7	9.6	6.2	5.0	18.5	1808
6	QP46	2017/11/15	1.2	0.9	9.5	4.4	2.7	40.0	1742
7	QP47	2017/11/20	3.7	2.19	29.3	14.8	5.4	23.7	834
8	QP18	2017/12/3	2.1	0.6	65.8	6.5	4.6	29.4	1829
9	CP52-12	2019/5/18	4.0	3.0	9.7	22.1	15.5	29.1	9893
10	CP52-10	2019/5/18	3.7	2.7	12.8	10.9	9.7	12.1	4224
11	CP52-11	2019/7/12	5.0	3.1	25.7	18.4	13.2	26.5	7332
11 in total			32.4	21.2	28.5	108.1	72.5	28.3	34288

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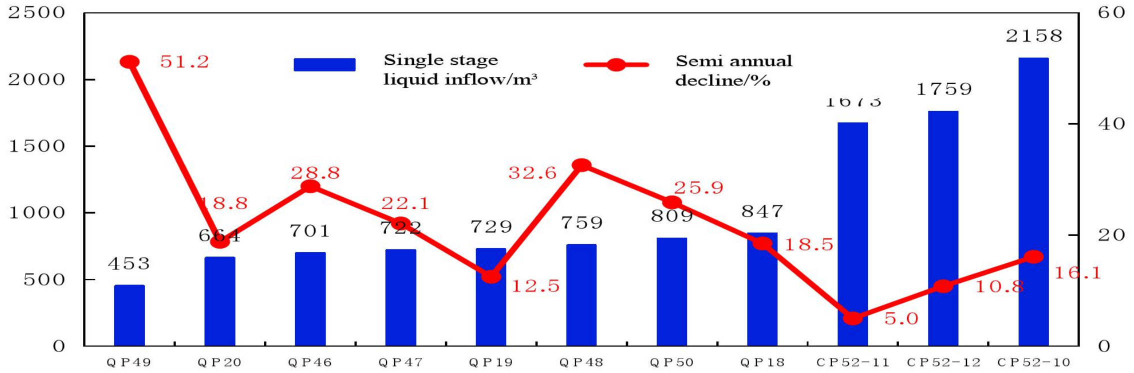

Figure9. Comparison diagram of annual large-scale volume fracturing fluid inflow in single section of horizontal well and semiannual decline

4. Conclusion and understanding

(1) The physical properties of ultra-low permeability reservoir are poor, and conventional water injection development is difficult to adapt to the current development level. Change the new mode of water injection development, and form a "injection pressure stuffy production" technology integrating comprehensive energy supplement, old fracture plugging, synchronous transformation and volumetric fracturing. It can realize the transformation of seepage from linear flow to complex fracture network, and form a new development mode that can be copied and popularized, It provides a reference for the development technology of horizontal wells in ultra-low permeability reservoirs.

(2) Through numerical simulation and actual field test, it is concluded that when the energy storage formation level is maintained at 110-120% before large-scale volume fracturing and the liquid inflow of a single well is 8000 ~ 10000m3, at the same time, the capacity expansion after fracturing can significantly increase the reservoir imbibition and displacement, and the well plugging time is the best between 40-60d, so as to maximize the utilization of reserves.

(3) The large-scale volume fracturing of horizontal wells in yuan284 area has achieved good results. For the volume fracturing of conventional horizontal wells, the average daily oil production of horizontal wells is more than 10.0 tons after the test. It is predicted that the final recovery rate will be increased from 5.3% to 12.3%, and the single well production and recovery rate in the test area will be greatly improved.

Acknowledgments

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