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Research and application of large-scale fracturing imitating horizontal well technology in vertical well

Song Yang *

Exploration and Development Research Institute of Daqing Oilfield, Daqing, China

Abstract. Hailaer Basin is rich in geological reserves, but the proportion of undeveloped reserves is high, accounting for 30% of the proved reserves. In order to improve the production degree of reserves and single well production, and realize the purpose of high and stable production of the oilfield. Taking the ultra-low permeability reservoir of oilfield B in Hailaer Basin as an example, this paper puts forward the large-scale fracturing of vertical wells and water injection development technology of imitating horizontal wells. By forming directional ultra long fracturing fractures in the oil layer, this technology can effectively increase the reservoir conductivity, increase the oil well drainage area and water well control area, reduce the well pattern density and improve the production of single well. The research shows that the undeveloped reserves in Hailaer oilfield have the characteristics of low thickness, low permeability and low reservoir quality index. There are 55 large-scale mold fracturing wells in Hailaer oilfield, with an initial oil increase of 2.2 times. The sand amount of large-scale fracturing is 2.5 times that of ordinary fracturing, and the fluid amount and sand intensity are 4.5 times that of conventional fracturing. The vertical well large-scale fracturing imitating horizontal well technology is adopted in Oilfield B. The designed vertical well fracturing fracture is 600m long and 120m wide, and the production effect is good after fracturing. The research results are of great significance to the high and stable production of undeveloped reserves block in Hailaer oilfield and other similar oilfields.

Key word: Ultra-low permeable reservoir; starting pressure gradient; large-scale fracturing; imitation horizontal well.

1. Introduction

With the continuous development of oil fields, the oil production decreases year by year, and the national demand for energy is increasing. In the face of this phenomenon, each oil field gradually strengthens the research on the development technology of proved undeveloped reserves. Xiaowa oilfield adopts the technology of viscosity reduction, plugging removal and rush pumping and forced drainage to realize effective gas injection development and improve the degree of reserve production. Wa 79 well area of Liaohe Oilfield adopts the combination of horizontal well and gas injection, and uses multi-point gas injection to improve heat utilization efficiency and realize the effective development of difficult to recover reserves. Facing the gas injection sources and high investment cost of horizontal wells, these methods have certain limitations in Hailaer oilfield. Therefore, in order to realize the economic and effective development purpose of low investment and high production, this paper puts forward the water injection development mode of large-scale vertical well fracturing imitating horizontal well, so as to give full play to the role of well pattern, realize economic and effective development and improve the production degree of undeveloped reserves.

2. Characteristics of undeveloped reserves in Hailaer Oilfield

2.1 Characteristics of reserve parameters and pore structure parameters

Statistical comparison of the reserve parameters and pore structure parameters of developed and undeveloped fault blocks in Hailaer oilfield shows that the average effective thickness of undeveloped fault blocks is 6.1m, the permeability is 7.0mD and the reserve abundance is 35.4 $\times 10^4 t / km^2$, with the characteristics of small fault block, low thickness, low permeability, low reserve abundance and low mobility.

* Corresponding author: songyangyy123@sina.com

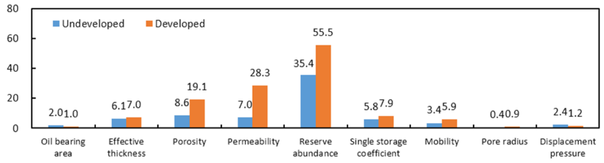

Figure 1. Comparison of parameters between developed and undeveloped areas of Hailaer Oilfield

2.2 Reservoir quality index characteristics (RQI)

Reservoir quality index is an effective method to study the physical classification of reservoir rocks, and it is also an important parameter to reflect the variation characteristics of micro pore structure.

The blocks of Hailaer oilfield are divided into development blocks and undeveloped blocks. The reservoir quality index of each block can be calculated according to the porosity and permeability parameters of each block. From the scatter diagram of the relationship between reservoir quality index and porosity, it can be seen that the developed areas are mainly in φ > 10. RQI > 5 area, undeveloped area φ < 10. RQI < 5 area. It shows that the overall quality index of Hailaer oilfield is low.

$$RQI = 0.0314\sqrt{\frac{K}{\varphi}}$$

Remarks: RQI is the reservoir quality index; K is permeability, mD; φ is porosity,%.

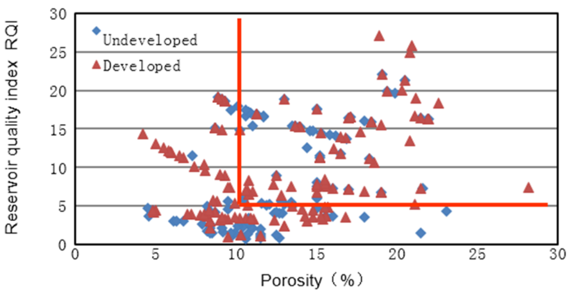

Figure 2. Scatter diagram of the relationship between porosity and reservoir quality index in developed and undeveloped blocks

2.3 Characteristics of starting pressure gradient

2.3.1 Effect of starting pressure gradient on production

Experts and scholars at home and abroad have conducted a large number of experimental studies on ultra-low permeability reservoirs and found that there are non Darcy flow characteristics in ultra-low permeability reservoirs, that is, there is a phenomenon of starting pressure gradient. When the permeability is higher, the starting pressure gradient is lower and the single well production is higher; The smaller the permeability, the higher the starting pressure gradient and the lower the single well production [1,2].

2.3.2 Effect of starting pressure gradient on effective driving distance

According to the experimental data of starting pressure gradient in Hailaer oilfield, the relationship curve between starting pressure gradient and permeability is drawn, and through curve regression can be obtained the relationship between the starting pressure gradient λ and permeability K is as follows:

$$\lambda = 0.0288K^{-0.533}$$

Remarks: λ is the starting pressure gradient, MPa / m; K is permeability, mD.

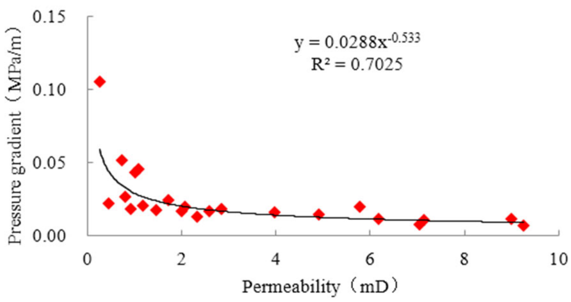

Figure 3. Relation curve between starting pressure gradient and permeability

In the hydrodynamic field of steady radial flow with equal output source and sink, the seepage velocity on the mainstream line is the largest, while on the same streamline, the seepage velocity at the same distance from the source and sink is the smallest. The starting pressure gradient here is:

$$\frac{P_H - P_W}{\ln\frac{R}{r_w}} \cdot \frac{2}{R} = \lambda$$

Remarks: P_h is the bottom flow pressure of water injection well, MPa; P_w is the bottom hole flow pressure of production well, MPa; R is the limit injection-production well spacing, m; R_w is the wellbore radius, m.

According to the actual situation of the oilfield, given the injection production differential pressure and starting pressure gradient parameters, the limit injection-production well spacing under the condition of low production pressure can be calculated by the above formula is about 150m.

Because the undeveloped reserves in Hailaer Basin have the above characteristics, the conventional fracturing method can not meet the economic and effective development of the oilfield. Therefore, large-scale fracturing is needed to improve the reservoir conductivity, increase the oil drainage area and improve the production of single wells.

3. Large scale fracturing effect analysis

3.1 Fracture shape analysis

According to the statistics of the relationship between the fracturing scale of large-scale branch fracture fracturing wells in the periphery of Daqing placanticline and the length width ratio of fractures, it can be seen that under the fracturing scale of a certain amount of sand and liquid, the average length width ratio of artificial fractures is 3.0. When the sand liquid ratio is increased, the fracture length width ratio is further increased, basically reaching more than 3.5.

Table 1. Statistical results of fracturing scale and artificial fracture length width ratio

Well number	Fracture thickness（m）	Fracturing fluid (m^3)	Sand addition (m^3)	Add liquid strength (m^3/m)	Sanding strength (m^3/m)	Sand liquid ratio（1：x）	Crack network length（m）	Crack network width (m)	Crack network height (m)	Crack length width ratio
P174-392	15.5	4400	135	284	9	33	218	84	50	2.6
Z73-49	7	3594	80	513	11	45	248	75	53	3.3
S98-39	10.2	4314	56	423	5	77	220	86	8	2.6
N210-X284	4.5	2634	50	585	11	53	222	82	58	2.7
Y258-D140	16.4	7283	90	444	6	81	259	59	65	4.4
P160-352	19.3	6650	110	345	6	60	390	183	22	2.1
P164-352	13.8	9210	115	667	8	80	388	201	18	1.9
P162-X352	16.7	7700	120	461	7	64	454	309	25	1.5
T283-52-X52	13.7	8473	241	618	18	35	298	82	10	3.6
T283-66-X56	5.5	4643	103	844	19	45	357	95	28	3.8
Average	11.4	5529.9	102.5	537.1	10.1	57.3	321.5	114.6	35.1	3

3.2 Fracturing scale analysis

According to the statistics of the construction parameters of conventional fracturing and large-scale fracturing in Hailaer oilfield, it can be seen that the sand adding amount of large-scale fracturing is 2.5 times that of ordinary fracturing, and the liquid adding amount and sand adding intensity are 4.5 times that of conventional fracturing, forming 3-4 branch fractures. There are micro fractures near the well, with an artificial fracture width of 80-100m, a fracture length of 250-390m and a sand adding amount of 100-150m^3.

Table 2. Comparison of construction parameters of conventional fracturing and large-scale fracturing

Oil field	Horizon	Initial conventional fracturing			Conventional fracturing again			Large scale fracturing again		
		Sand addition（m^3）	liquid addition（m^3）	Sanding strength（m^3/m）	Sand addition（m^3）	liquid addition（m^3）	Sanding strength（m^3/m）	Sand addition（m^3）	liquid addition（m^3）	Sanding strength（m^3/m）
B	X	62.6	496.4	1.3	78	531.9	2.6	146	1706	9.7
	B	57.0	465.3	1.4	60	392.2	2.7	120	1890	7.8
	N	42.6	359	2.1	42.3	339.7	2.0	112.1	1820	8.3
W	N	34.8	279.9	2.8	54.3	504.1	1.9	108.1	1883	8.8
Average		49.3	400.2	1.9	58.7	442	2.3	121.6	1824.8	8.6

3.3 Production analysis

Hailaer oilfield has implemented a total of 55 large-scale fracturing wells. The average daily oil production of a single well before fracturing is 0.6 ~ 2.3t, the average daily oil production of a single well after large-scale fracturing is 2.9 ~ 4.7t, and the oil increase multiple at the initial stage of large-scale fracturing is 1.4 ~ 5.8 times, with an average of 2.2 times.

Large scale fracturing generally improves the water absorption capacity of water wells, with water injection volume of 30-40m^3 and water injection pressure of about 20MPa. Water injection development is realized in the well area. Large scale fracturing improves the seepage capacity of inter well reservoir. Skid mounted water injection can realize effective injection. Well groups with good injection production connection have good oil increase effect after receiving effect.

Table 3. Production increase multiples of Hailaer Oilfield Block

Block	Number of wells	Average daily oil production per well (t)		Oil increase multiple
		Before fracturing	After fracturing	
X	24	1.4	4.7	3.4
BN1	12	1.3	2.9	2.2
BD	6	2.3	3.2	1.4
WN1	10	0.6	4.4	7.3
BN2	3	0.8	4.6	5.8

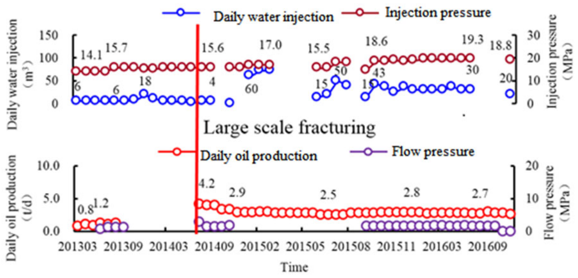

Figure 4. Water injection production curve of well cluster X58-54

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To sum up, adopting large-scale fracturing technology to exploit Hailaer oilfield has achieved good development results, and this technology is also an effective means to exploit the undeveloped reserves of Hailaer oilfield. Based on the continuous rise of oil price at present, in order to achieve the purpose of low investment and high production, it is necessary to optimize and adapt the "large-scale fracturing" and "injection production well pattern", reduce the well pattern density and achieve an effective breakthrough in the production technology of undeveloped reserves.

4. Research on water injection development technology of imitation horizontal well

Based on the idea of water injection development of horizontal wells, the scheme of large-scale fracturing of vertical wells imitating horizontal wells is designed. Through large-scale fracturing of vertical wells, directional ultra long fracturing fractures are formed in the oil layer, which is equivalent to drilling through a horizontal section hundreds of meters long in the oil layer. From the schematic diagram of fracturing half fracture length, oil well drainage area and water well control area, it can be seen that with the increase of fracturing half fracture length, the oil well drainage area and water well control area also gradually increase [3-5].

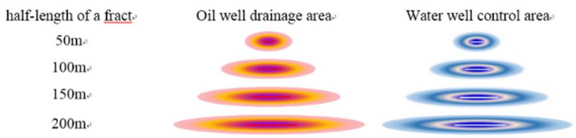

Figure 5. Control area of oil and water wells with different fracture lengths

At the same time, considering the influencing factors of in-situ stress direction, combine the fracturing long fracture with the well pattern, optimize the design of injection production well pattern, and timely inject water linearly into the fracturing well, so as to achieve the purpose of water injection, obtain higher recovery, reduce drilling, reduce investment, greatly improve recovery and economic benefits, and realize the economic and effective development of ultra-low permeability reservoir.

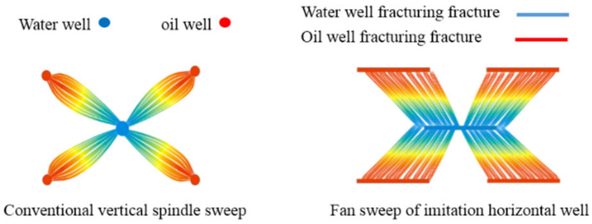

Figure 6. Comparison between vertical well and imitation horizontal well

Due to the high investment cost of large-scale fracturing, in order to reduce investment risks and improve economic benefits, according to the technical requirements and economic boundary requirements of large-scale fracturing of imitation horizontal wells, combined with the analysis of previous large-scale fracturing effects, the applicable conditions of water injection development technology of imitation horizontal wells are formulated: ① in order to realize the directional extension of the length of main fractures, the ratio of the maximum horizontal stress difference coefficient to the minimum horizontal stress difference coefficient should be ≥ 1.5 on the plane; ② Permeability ≤ 20 mD, small physical properties, large increase of oil drainage radius after pressure; ③ Since the overall fracturing requires a certain oil-bearing area, the oil-bearing area needs to be ≥ 0.5 km^2; ④ In order to ensure that the oil well after fracturing has a certain production capacity, the thickness of oil layer shall be ≥ 5m; ⑤ In order to prevent pressure channeling reservoir, oil-water distribution requires oil layer or dry layer; ⑥ In order to avoid conflicts between layers, the perforated well section shall be ≤ 50m.

5. Case analysis

5.1 Block overview

Fault block B is located in the west of sudelte structural belt. The elevation of the high point of fault block structure is about - 1025m. The stratum is high in the northwest and low in the southeast. It is a slope zone cut by NE trending clockwise fault, and the stratum dip angle is about 11 °. The maximum principal stress azimuth is 70 ° ~ 115 °, with an average of 96.6 °. The average effective thickness of the single layer of the main small layer of oil group I of oil layer X is 1.0 ~ 2.0m, and the average effective thickness of the single layer of the main small layer of oil group II is 1.0 ~ 2.2m. The thickness of the oil layer is small. The average porosity is 16.3% and the average permeability is 1.59mD. It is a medium porosity and ultra-low permeability reservoir. The average permeability variation coefficient of oil group II of oil layer X is 1.34, the breakthrough coefficient is 4.82, the permeability grade difference is 48.14, and the heterogeneity is serious.

5.2 Effect analysis

According to the prediction results of seismic and geological reservoir sand body in fault block B, aiming at maximizing the effective fracture swept volume, the integration method of vertical well directional long fracture fracturing imitating horizontal well and well pattern optimization design is adopted to realize the purpose of increasing fracture controlled reserves, expanding well spacing and reducing well pattern density. The designed vertical well fracturing fracture is 600m long and 120m wide.

Seven development wells are deployed in Block B, including one initial well, five normal wells and one substitute well. New capacity 0.72×10^4t, producing area of 0.87km^2, producing geological reserves of 55.90×10^4t. At present, four wells in operation have achieved good fracturing effect, and the cumulative oil production in the elastic production stage is 1641t on average. After half a year of operation, water injection development is started. In the first year, the average daily water injection is 57m^3 and the water injection pressure is 18.5MPa.

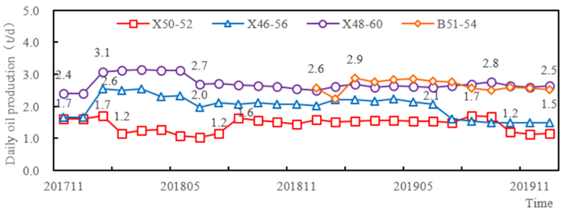

Figure 7. Production curve of production well in B block

6. Conclusion

The undeveloped reserves in Hailaer oilfield are characterized by small fault block, low thickness, low permeability, low abundance and low mobility. With the arrival of the middle and late stage of oilfield development, the development of undeveloped reserves will become an important part of stable production of the oilfield.

There are non Darcy flow characteristics and starting pressure gradient in ultra-low permeability oilfields. The greater the permeability, the lower the starting pressure gradient; The smaller the permeability, the higher the starting pressure gradient.

There are 55 large-scale fracturing wells in Hailaer oilfield, with an initial oil increase of 2.2 times. The sand adding amount of large-scale fracturing is 2.5 times that of ordinary fracturing, and the fluid adding amount and sand adding intensity are 4.5 times that of conventional fracturing. With a certain amount of sand and fluid, the average length width ratio of artificial fracture is 3.0.

The water injection development technology of imitating horizontal wells can effectively increase the conductivity, increase the fracture controlled reserves, expand the well spacing and improve the production of single wells; Achieve the purpose of greatly improving oil recovery and economic benefits, and promote the production and development of undeveloped reserves in Hailaer Basin.

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