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STUDY OF REASONABLE WELL PLANNING FOR TERTIARY INFILLING IN XING6 AREA, DAQING OILFIELD

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***Abstract*—Daqing Oilfield is the most important and the biggest oil field in China, with forty-five years water flooding development, the reservoir in Xing6 area is in high water cut stage of development. The scatter distribution of remaining oil and the poor development on thin and poor oil layers are present problems. After the adjustment of secondary infilling implemented in 1996, the recovery degree of low permeability and thin layers has been improved, but the development on tabulated thin reservoir (effective thickness between 0.2~0.5m) is still poor, especially the un-tabulated reservoir (effective thickness below 0.2m). In response to the sand layers with effective thickness below 0.5m, the tertiary infilling stage is implemented. On the basis of elaborate reservoir geological description, and using the skills of comprehensive description of the remaining oil, we analyze the features of remaining oil, as well as all types of layers' washing condition and adjustable sandstone thickness after secondary infilling in Xing6 area. The results indicate that the Xing6 reservoir has certain potential for tertiary infilling adjustment. In this paper, we adopt the "three combinations" policy, combined tertiary infilling adjustment with original well pattern, combined tertiary infilling adjustment with water flooding regime modification, and combined tertiary infilling adjustment with later tertiary oil recovery, to optimize well distribution. Through the adjustment of the well pattern, injector producer distance, well density, water flooding system, etc., the perfect water flooding regime is achieved to fully produce the remaining oil of the sand layers with effective thickness below 0.5m. The good results have been achieved in Xing6 area. After the adjustment of tertiary infilling, the Xing6 area recovery ratio increases 2.72%, the flooding control degree of tabulated thin reservoir (effective thickness between 0.2~0.5m) and un-tabulated reservoir (effective thickness below 0.2m) increase 4.23% and 9.69%, and formed the matching tertiary infilling techniques.**

***Index Terms*—remaining oil, tabulated thin reservoir, un-tabulated reservoir, tertiary infilling, Xing6 area.**

I. INTRODUCTION

The Xing6 area reservoir in Daqing Oilfield is located in Heilongjiang Province between An'da city and Qijia town (see Figure 1). The sedimentary type is River-delta sedimentary system. Reservoir depth is 800~1200m, the average sandstone thickness is 75.6m, the average effective thickness is 26.4m. Original oil in place of Xing6 area is 6510 t, however, usable reserves (contained by tabulated reservoirs[1]-[3], which includes tabulated thick reservoirs and tabulated thin reservoirs) is 5346 t, useless reserves (contained by un-tabulated reservoirs) is 1164 t. The development of tabulated thin reservoirs (stands for the sand layers with effective thickness between 0.2m and 0.5m) and un-tabulated reservoirs (stand for the sand layers with effective thickness under between 0m and 0.2m) are better.

After the second infilling implemented in 1996, the recovery degree of tabulated thin reservoirs has been improved, but the development of un-tabulated reservoirs is still poor [4]-[5]. Up to the end of December 2010, in Xing6 area, the formation pressure is 8.89, composite water cut is 92.6%, water flooding well spacing density is 37.7 wells/km2 and recovery is 42.75%, which has entered the high water cut, high degree of reserve recovery, high well spacing density development period. In the present well pattern control, it is difficult to produce the remaining oil. Therefore, through the research and analysis of remaining oil of tabulated thin reservoirs and un-tabulated reservoirs, we deduced that Xing6 area has a certain potential for tertiary infilling.

II. POTENTIAL ANALYSIS OF TERTIARY INFILLING

A. *Features of remaining oil distribution*

The distribution of remaining oil in Xing6 area can be divided into two types, poor water absorption and injection production imbalance. For each single well, the remaining oil layer number of poor and thin reservoirs is 16.9. The overlay thickness of remaining oil layer is 10.1m and the effective thickness is 0.8m. In the poor and thin reservoir, the overlay thickness of remaining oil layer accounted for 23.4% of the total thickness of non-essential reservoir. The poor water intake layers number accounted for 63.9% of the total number of remaining oil layers, and the injection production imbalance layers number accounted for 32.1% of the total number of remaining oil layers.

The main concentration of remaining oil is in the first un-tabulated reservoir and second un-tabulated reservoir. From the sealed coring data, in non-essential reservoir, tabulated thick reservoir (the sand layers with effective thickness above 0.5m) were all flooded by water, the flooding thickness ratio of tabulated thin reservoir (the sand layers with effective thickness between 0.2~0.5m) is 97.1%. The first and second un-tabulated reservoir flooding thickness ratios are 69.5% and 43.7%. The number of first and second un-tabulated reservoir respectively accounted for 51.0% and 32.8% of the total number of remaining oil layers, respectively accounted for 55.0% and 26.4% of the total thickness.

The distribution of remaining oil is highly dispersed. Vertically, there are 12.2 remaining oil layers for every 100 meters, and most remaining oil layers and breakthrough layers were interactive distribution. From the distribution of remaining oil in single layer, we can know the distribution of remaining oil is scattered in the plane, the control degree of water flooding is low, which result the production difficultly.

B. *All types of layers' washing condition*

As we can see from Table 1, for the sand layers with effective thickness above 2m, the flooding thickness ratio and recover degree are increasing with the well spacing density increasing. Before the tertiary infilling, recovery degree reached 47.8%, water flooded layers ratio is 100%, and water flooded thickness ratio reached 93.2%.

Coring time	coring Well /wells	flooded layers ratio /%	flooded thickness ratio /%	Displaced efficiency /%	Recovery /%
Before first infilling	2	80.0	61.6	55.70	34.3
first infilling	2	100	75.9	51.30	38.9
Secondary infilling	2	100	93.2	51.30	47.8

Table.1 Sand layers (effective thickness above 2m) washing condition at different development stages

As we can see from Table 1, the recover degree of tabulated thin reservoir is increasing with the well spacing density increasing, but the recovery degree is low. Before tertiary infilling, the water flooded layers ratio and water flooded thickness ratio of tabulated thin reservoir are 80.3% and 65.7%, the recovery degree is only 27%. Compared with tabulated thin reservoir, the recovery degree of un-tabulated reservoir is lower, before secondary infilling, the recovery degree of un-tabulated reservoir is 0, and before tertiary infilling, the recovery degree can only reach 6.4%. The main reason of poor production degree of un-tabulated reservoir is the reservoir thickness is getting thinner.

By comparing Table.1, Table.2 and Table.3, we can know that after the secondary infilling, the recovery degree of tabulated thin reservoir and un-tabulated reservoir had been improved, but the production degree is still poor. The main object of tertiary infilling is un-tabulated reservoir and the layers with effective thickness below 0.5m.

Table.2 Sand layers of tabulate reservoir washing condition at different development stages

Coring time	coring well /wells	flooded layers ratio/%	flooded thickness ratio/%	displaced efficiency /%	recovery /%
Before first infilling	2	18.0	14.9	41.3	6.1
first infilling	2	37.1	36.9	39.4	14.5
secondary infilling	2	80.3	65.7	41.1	27.0

Table.3 Sand layers of un-tabulate reservoir washing condition at different development stages

Coring time	coring well /wells	flooded layers ratio/%	flooded thickness ratio/%	displaced efficiency /%	recovery /%
Before first infilling	2	/	/	/	/
first infilling	2	/	/	/	/
secondary infilling	2	25.6	14.5	43.9	6.4

C. Adjustable Sandstone Thickness

We used neural network method to analyze the remaining oil of 897 production wells and 102 sand layers layer by layer [6]-[8]. When the interlayer thickness is 1m, the average adjustable sandstone thickness is 8.77m, adjustable effective thickness is 1.43m, and reduced effective thickness is 3.26m.

In order to accurately predict the adjustable sandstone thickness of tertiary infilling, we selected 20 new wells to simulate the perforation. The results show that when the interlayer thickness is 1m, the prediction of adjustable sandstone thickness is 13.08m, adjustable effective thickness is 0.85m, and reduced effective thickness is 3.91m.

From the above two methods, we can determine the adjustable sandstone thickness is 9.7m, adjustable effective thickness is 1.1m and reduced effective thickness is 3.25m. Therefore, the Xing6 reservoir has certain material base for tertiary infilling adjustment, but it is difficult to produce.

III. Adjustment Method of Tertiary Infilling

A. Reasonable well pattern

The statistical results show that after secondaryinfilling adjustment, the tabulated thin reservoir control degree and the un-tabulated reservoir control degree of water flooding are 79.9% and 72.5% [9]. One way connectivity rate of tabulated thin reservoir and un-tabulated reservoir are 28.8% and 34.7%, but the multidirectional connectivity rate of tabulated thin reservoir and un-tabulated reservoir are only 21.4% and 13.4%, which is not conducive to the reservoir production. The main reason of poor multidirectional connectivity rate is injection-production well pattern is imbalance, the injector producer ratio is 1:1.6. Therefore, we need to appropriately increase the number of injection wells and to keep the voidage-injection balance of thin and poor reservoir. By comparing the effect of three different well spacing patterns include line flooding, five-spot pattern and inverted nine-spot flooding pattern, we can know the average control degree of five-spot flooding pattern is 8%~10% higher than other well patterns, and the recover degree is higher than other well patterns when the water cut is same. Meantime, compared with other well patterns, five-spot pattern is easy to be modified in late development [10]. Therefore, we should adopt the five-spot flooding pattern for the tertiary infilling adjustment.

B. Rational Spacing between Wells

The main production formations of tertiary infilling adjustment are tabulated thin reservoir and un-tabulated reservoir. Due to the poor reservoir property and large filtrational resistance, in order to establish an effective injection-production driving pressure differential, the injector producer distance should not be too long. Because of the existence of threshold pressure gradient in low permeability reservoir, with the decrease of permeability, a sharp increase of threshold pressure gradient. Through core displacement test, we can get the relationship expression between threshold pressure gradient and permeability of un-tabulated reservoir.

$$\frac{\Delta p}{L} = 0.3893K^{-0.7916} \quad (1)$$

Where, Δp is injector producer pressure difference; L is injector producer distance; K is permeability, $10^{-3}\mu m^2$.

The results show that, under the condition of permeability is 5×10-3 μm^2 and injector producer distance is 200m, only when the injection production pressure difference and injection pressure are greater than 21.78 MPa and 14.09 MPa, so that this part of un-tabulated reservoir can be produced. However, in the current development situation, it is very difficult to achieve this value of injection production pressure difference. Therefore, if we want to produce this part of un-tabulated reservoir effectively, the injector producer distance need be controlled within 170m.

According to the results of production wells annulus logging in Xing5 area, with the decrease of injector producer distance, the recovery degree of un-tabulated reservoir increases. When the injector producer distance is less than 150m, the production degree of un-tabulated reservoir can reach more than 60%. So the injector producer distance should be 100~150m.

IV. WELL SPACING PRINCIPLES OF TERTIARY INFILLING

A. Combined with Original Well Pattern

Tertiary infilling adjustment is based on the secondary infilling to improve the injection production relationship of poor and thin layers. Because of the secondary infilling well pattern limitation, the tertiary infilling wells deployment should be combined with the old wells and comprehensive consideration of well spacing pattern [11]. The producing object is different at different development stages, and the perforated sand layer number ratio is also different. From the basic well pattern to the tertiary infilling, the perforated sand layer number ratio of tabulated thick reservoir (effective thickness is between 0.5~2m) decreased gradually, the perforated sand layer number ratio of tabulated thin reservoir (effective thickness is between 0.2~0.5m) and un-tabulated reservoir (effective thickness is below 0.2m) are increasing. If the old well type is same with tertiary infilling well type, the well distance should be greater than 50m; if the old well type is different from tertiary infilling well type, the well distance should be greater than 80m. At the same time, in order to prevent the casing failure, the water wells are not deployed near the fault in principle.

B. Combined with Water Flooding Regime Adjustment

According to the real problems in Xing6 area, we take water flooding regime adjustment for poor and thin layers' well pattern, structure and casing failure, and voidage-injection imbalance these three kinds of influence factors. The results are shown in Table.4.

Table.4 water flooding regime adjustment for poor and thin layers

Influence factor		problems	Adjustment method
Well pattern		The low injector producer ratio, low flooding control degree and poor feed flow ability	Invert the corner wells of inverted nine spot pattern or some oil wells of irregular five spot pattern into water wells, so as to form the suitable well pattern for different types of single sand body
Local well field	Structure and casing failure	Low control degree of sand body	Drill additional well, overhaul, updating, etc.
Injector producer imbalance of single sand body	Oil well perforation, injection well without perforation	Production without injection	Reperforate injection well or increase the water injection well
	Injection well perforation, oil well without perforation	Injection without production	Reperforate oil well
	Oil well and injection well without perforation	No production and no injection	Reperforate oil well and injection well
	Sandbody property of oil well or injection well get poor	Poor effect	Transform by treatments
	Other oil well perforation between oil well and water well	Second line effect	increase the water injection well

C. Combined with Later Tertiary Oil Recovery

Tertiary infilling adjustment should be combined with later tertiary oil recovery, in order to improve the comprehensive utilization rate of well pattern and improve the economic benefit [12]-[14]. Xing6 reservoir has not yet been carried out the tertiary process. According to the experience of adjacent areas have been carried out the tertiary oil recovery, if we implement hyper concentration polymer flooding in Xing6 area, the final recovery can be increased of 15%. On the basis of water flooding regime adjustment of poor and thin layers (effective thickness is below 0.5m), we analyze the combination flooding and polymer flooding in poor and thin layers, the final recovery can be increased more than 10%.

V. RESULTS

After the adjustment of tertiary infilling, the average production of oil well is 2.58t/d, water cut is 81.61%. The basic well oil production is 3.5t/d; the average production of infilling wells is 2t/d; the tertiary oil recovery wells production is 3.3t/d, water cut is 92.76%. Recovery rate has been increased by 2.72%, water flooding control degree of un-tabulated reservoir increased by 9.69%. Tabulated reservoir and un-tabulated reservoir one-way connected layers were reduced by 13.45% and 12.42%, and tabulated thin reservoir and un-tabulated reservoir multi connected layers were increased by 18.43% and 17.1%. Increment of multi connectivity rate improved the producing degree of tabulated thin reservoir, and slowed down the decrease of old wells production, prolong the stable production period. After the tertiary infilling, the effect in Xing6 area has been improved obviously.

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