Characterization of water flooded layers of alluvial fan reservoirs in China Xinjiang oil field

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Abstract

Alluvial fan reservoirs have strong heterogeneity, which would result in complicated remaining oil distribution in mid-late water injection development stage of oilfield. To assess the flooding degree of water flooded layers and find out the remaining oil distribution law are important and difficult in oil field developing adjustment. The paper took Kexia formation reservoirs in Xinjiang oil field for example, and on base of establishing the criterion of identification of water flooded layers, the reservoir flooding degree and features were analysed. The remaining oil distribution model of alluvial fan reservoirs were divided into 4 categories: injection-production without corresponding, oil layers on top, interface barrier type and lenticular type. The effect of sedimentary facies to remaining oil distribution was concluded: the middle fan reservoirs are the main target of tapping potential, interbeded of multi-period braided river distributary channel deposition and sheetflood fine particle deposition, which has strong heterogeneity and result in low swept volume of displacement of oil by water. And their distribution models mostly are layers on top type and interface barrier type.

Keywords: alluvial fan reservoirs; remaining oil; Kexia formation; water flooding oil field; high water cut stage

1 Introduction

The Kexia formation reservoirs in Liuzhongdong area in Xinjiang oil field is a fault block between the Ke-wu fracture and the north Baijiantan fracture. It is mainly dominated by lamellar flow deposit of middle fan inner zone of alluvial fan [1-3], which has strong heterogeneity [4]. Now the oil reservoirs have entered high water cut stage after more than 40 years of development, which show up the water cut increasing rate is fast and the difference of water flooding degree in oil reservoirs are big [5,6]. The remaining oil distribution in high water cut oil field is complicated [7-14]. There were former researches talked about the characteristics of reservoirs and water flooded degree, as well as their relations in complicated conglomerate reservoirs, and all tended to resolve the high water cut problems. On the basis of predecessors' research, the paper gave a new identification method of water flooded layers, and described the water flooded characteristics of every single layer by using the pressure coring data, drilling static data and production performance data. The remaining oil distribution model and controlled factors were concluded, which would be significant to the next step of remaining oil potential tapping.

2 Development of oil reservoirs

The Kexia formation in Liuzhongdong area in Xinjiang oil field is a rapid deposition piedmont diluvial facies sandy conglomerate bodies on the crust of weathering of metamorphic rocks-igneous rock in Carboniferous. The source direction are mainly come from north and northwest, and the metamorphic rocks, intrusive rock and basement of sediment trap in north mountains are parent rocks. The sedimentary thickness is between 45 m to 77 m, and an average of 52 m. From bottom to up the Kexia formation is divided into two sand groups S7, S6, and then divided into seven single layers, which subdivide into eleven single layers S61, S62, S63, S71, S72-1, S72-2, S72-3, S73-1, S73-2, S73-3, S74 at the high water cut stages of development.

The Kexia formation in this region is mainly deposits of retrogradation alluvial fan, and the climate change is from dry environment to half moist environment. From the bottom up, S74-S73 are root fan subfacies, S72 is middle fan subfacies, and S71-S63 are fan edge and floodplain subfacies. The reservoirs of root fan present the characteristic as continuous-flake distribution named extensive connecting sand body, which mainly contain the transverse discontinuous trench and lamellar flow gravel bar while the scale of fine particle deposition is less; the fan edge mainly contain the fine particle deposition of small scale and thickness run-off belts, and lateral is sealed by sheet flood fine particle deposition; the middle fan is the interbed of multiple phases braided distributary channel and sheet flood fine particle deposition, and the distributary channel bays are lateral cut, especially the architecture elements like sand dams and channels in the braided distributary channel are overlapped and have flow barrier by the existence of configuration interface]. From the bottom to the top the lithology from middle conglomerate, fine conglomerate to sandy conglomerate pebbly sandstone and fine siltstone, which means the granularity is from coarse to fine.

The oil reservoir′s characters of rapid accumulation determine the conglomerate reservoirs have strong heterogeneity in macroscopic and microcosmic view. From the bottom to the top the gravel content in every single sand layer is gradually decreased and the contents of sandy conglomerate and sandstone are gradually increasing. Generally speaking, there are the conglomerate accounts for 40%, the sandy conglomerate accounts for 19% and the sandstone accounts for 41%. The thickness of conglomerate

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reservoirs is large but interlayer development in it and the plane continuity is poor. The reservoir is mesopore and high permeability, and its average porosity is 19%, its average effective permeability is 250×10-3μm2, and in the middle the porosity and permeability are high, then become worse gradually to up and down; every single layer has strong in-layer heterogeneity with the coefficient of variation all greater than 0.7, the mutation coefficient all greater than 3, and the permeability level difference all greater than 200. Among them the S6 sands group and the S74 single layer have the most strong in-layer heterogeneity and the middle parts are weaker.

2.1 VERTICAL DISTRIBUTION OF OIL RESERVOIRS

There is no typical oil-water interface in the Liuzhongdong area and have oil in the whole area, and the reservoir's thickness could be 400 m at the most. The transverse distribution range of every single layer is very difference affected by the scale of sandy conglomerate bodies, and in S73-1-S74, the bottom of the Kexia formation, the sand bodies are vertical superimposed and have well reservoir connectivity; the distribution of sand bodies are smaller upward, and the reservoir connectivity get worse (Fig.1).

FIGURE 1 The oil reservoir profile of The Kexia formation in Liuzhongdong area

2.2 PLANAR DISTRIBUTION OF OIL RESERVOIRS

The plane oil bearing range of single sand layers S61, S62, S63 are fragmentary and generally 1-4 wells control one single sand body, no more than six wells. The plane oil bearing range of single sand layer S71 is larger. These three single sand layers S72-1, S72-2,S72-3 are main oil-bearing formation, and the range of pinch out area of sandy conglomerate bodies are small, while the overlapped oil bearing range are large and almost are continuous distribution, and from up to down the oil bearing range increases gradually. S73-1, S73-2, S73-3 also are main oil-bearing formation, and the S73-1 layer has pinch out area in the T6082 well area only; the S73-2 layer has pinch out area in the T6049 well area only, the oil bearing range is large; the S73-3 layer has the largest oil bearing range with its sandy conglomerate bodies are continuous distribution. The S74 single layer has no deposit in the southwest, but have oil-bearing formation in other well point, and the oil bearing range is large in general (Fig.2).

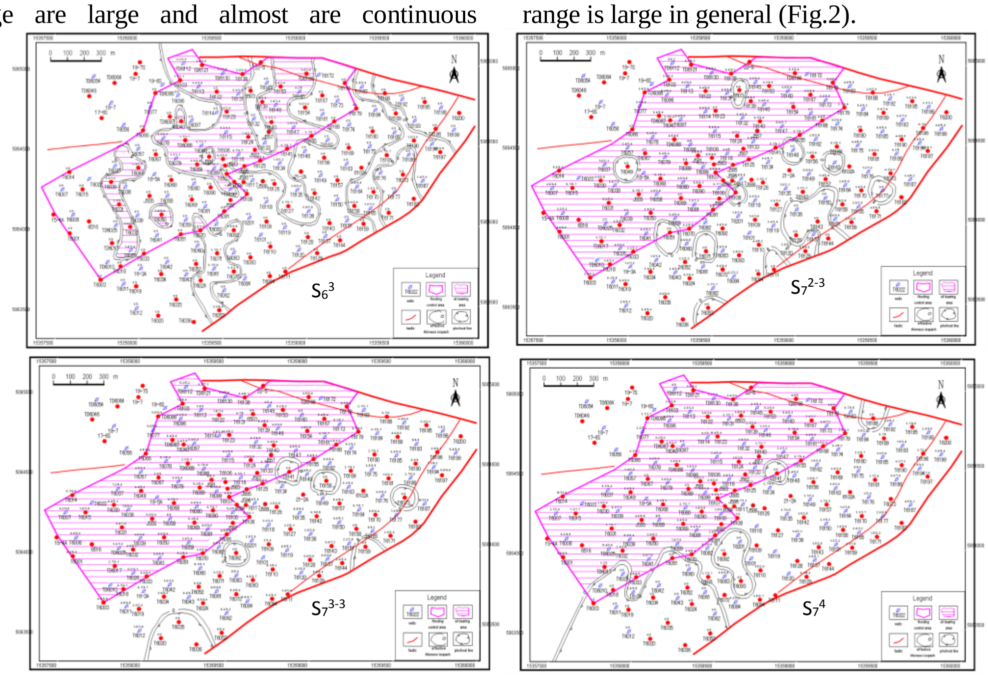

FIGURE 2 The oil-bearing area of S63, S72-3, S73-3, S74 in Liuzongdong area

3 Quantitative evaluation criterion of water flooded layer

To define water flooded grades of kinds of reservoirs, and to analyze the water flooded characteristics and their influencing factors are urgent needs to looking for remaining oil distribution of conglomerate reservoirs, and development adjustment as well.

The judgment of flooded layer does not rely on one parameter, for each influencing factor has particularity and it is probable that some parameters are quite sensitive for finding some kind of water flooded reservoirs, but not that sensitive for other kinds. To judge merely on the computer program sometimes leads to contradictions [15]. And it's necessary to use analysis of artificial intelligence. Study on data from 11 sealing coring wells, combined with the lithology, electricity, oiliness, core analysis, formation testing and production performance of water flooded layers of new drilling wells in this area, the identification criterion of water flooded layer of the conglomerate reservoir was established(Tab.1). The production data make it clear that the water flooded layers in this area are sensitive to 3 parameters: water production rate (Fw), oil saturation (So), displacement efficiency (Ed), so the quantitative evaluation of water flooded layers is mainly based on these 3 parameters, taking these factors into consideration meanwhile: deep resistivity, separation of deep and shallow resistivity, self-potential range, and baseline shifting of kinds of reservoirs.

TABLE 1 identification criterion of water flooded layer of Kexia formation in Liuzhongdong area

Lithology	Water flooded grade	Oil saturation So (%)	Displacement efficiency Ed (%)	Reservoir resistivity (Ω·m)	Water production rate Fw (%)
Sand	Oil	≥82	≤4	≥170	≤10
	Weak	82-68	4-20	170-100	10-40
	moderate	68-50	20-40	100-60	40-80
	strong	≤50	≥40	≤60	≥80
Sandy conglomerate	Oil	≥80	≤4	≥200	≤10
	Weak	80-70	4-20	200-130	10-40
	moderate	70-50	20-40	130-80	40-80
	strong	≤50	≥40	≤80	≥80
conglomerate	Oil	≥72	≤4	≥180	≤10
	Weak	72-64	4-20	180-110	10-40
	moderate	64-50	20-40	110-70	40-80
	strong	≤50	≥40	≤70	≥80

According to seepage theory of fluid mechanics, the calculating formula of water production rate is as follow:

$$F_w = \frac{Q_w}{Q_o + Q_w} = \frac{1}{1 + B \bullet \dfrac{K_{ro}\mu_w}{K_{rw}\mu_o}}, \quad (1)$$

Kro, Krw: relative permeability of oil, water, 10-3μm2;

μo, μw: viscosity of oil, water, mPas ;

B: parameter related to lithology and property, better lithology and property with smaller B value.

The oil saturation formula, which was matching by core data of Keshang formation, was used to calculate the original oil saturation of Kexia reservoirs, and then to calculate the displacement efficiency and the water flooded grade evaluation. The original oil saturation formula is as follow:

$$S_o = -11.054 * \lg(K/\phi) + 77.788$$

$$R^2 = 0.7748$$

So: original oil saturation, %;

K: permeability of reservoirs, 10-3μm2;

Φ: effective porosity, %.

After the original oil saturation of Kexia formation was calculated by the formula above, the displacement efficiency can be obtained:

$$E_d = \frac{(So - So')}{So}$$

Ed: water drive index;

So: original oil saturation, %;

So′: current oil saturation by calculation, %.

4 Water flooding characteristics of reservoirs

4.1 STATISTIC FEATURES OF THE WATER FLOODING LAYERS

The water flooding degree differ a lot of different thin layers of Kexia formation reservoirs in Liuzhongdong area in Xinjiang oilfield. The 8 sealing coring wells indicate that accumulating thickness of none flooding take up 17.8% of the total effective thickness, and merely in S73-1, and weak flooding take up 26.5%, and moderate flooding take up 34.9%, which is most popular, and strong flooding only take up 7.2%, which is quite small.

Through statistics on 165 developing wells, and cross well profile of injector- producer group, the moderate and strong flooded of single sand takes up an increasing percentage of 35% to 52%, from S73-1, S73-2 to S73-3. And the strong flooded mainly appear in S74 and S73-3, which are in the lower part of Kexia formation. Other layers exist strong flooded with small thickness although, they are generally moderate and weak flooded (Fig.3).

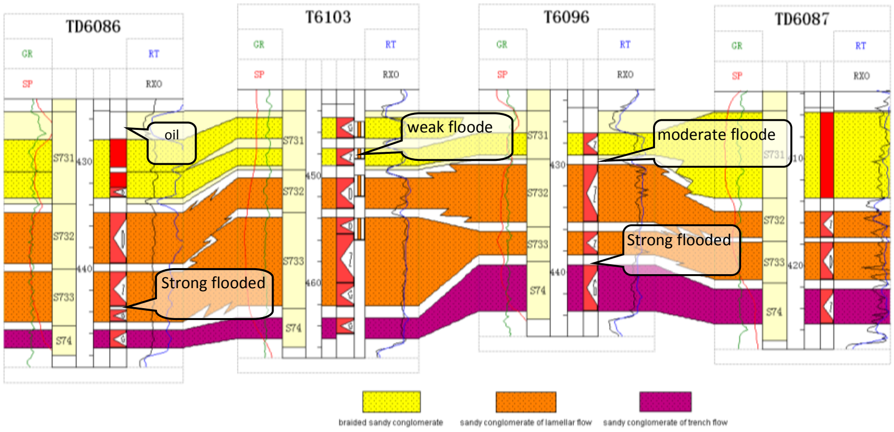

FIGURE 3 The cross well profile of TD6086-T6096-TD6087

The ratio of flooded thickness to sand thickness of thin layers of Kexia formation in Liuzhongdong area varies. And according to the thickness statistic of oil and flooded layers drilled by secondary developing wells in Liuzhongdong are, the layers with higher ratio of strong flooded are mainly in S74 and S63, while others are relatively weak. The percentage of moderate and strong flooded layers gradually decreases from S74 S73-1. That is to say, for the "extensive connecting sand body" in the lower section, the upper part has relative higher enrichment (Fig.4).

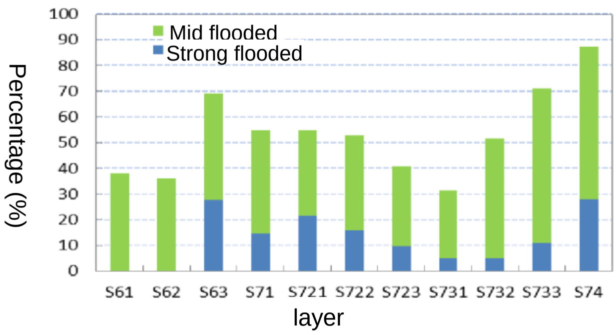

FIGURE 4 The percentage of the thickness of moderate and strong flooded layer in Kexia formation in Liuzhongdong area

4.2 VERTICAL FLOODED FEATURES OF RESERVOIRS

Comprehensive analysis on the flooded condition of secondary developing wells tells, for mainly the influence of lithology interface, rhythmicity, and thin interlayer, most reservoirs has inhomogeneous water flooded degree from up to bottom. Besides homogeneous flooding, the vertical flooding condition can be divided into 4 types: oil-weak flooded, weak-strong flooded, weak-moderate flooded, and weak-oil-moderate flooded.

Study on the 4 types of vertical flooding assembly, It's quite obvious that the perforation section will result in the water cut of oil wells. The practice shows that perforating weak flooded layers or weak flooded and oil layers, the oil wells have lower water cut, with composite water cut less than 40%. And perforating the strong flooded layers under weak flooded layers, the oil wells have higher water cut, with composite water cut higher than 80%. While perforating moderate flooded layers or moderate and oil, weak flooded layers, the oil wells have high composite water cut as well, generally higher than 40%. So, it's proposed to only perforate weak flooded layers or oil layers, and perforate moderate flooded with caution, and avoid perforating strong flooded layers.

4.3 REMAINING OIL DISTRIBUTION RULES AND MODEL

Kexia reservoir of Liuzhongdong area is a typical Conglomerate reservoir, with strong reservoir anisotropy, and the property difference between layers and strong reservoir anisotropy lead to the flooding degree difference of reservoirs. And it's quite obvious that the injected water fingering within the layers with relative high permeability. And it's general that the explaining results differ from the actual production condition, and the remaining oil distribution is complicated.

It's clear that controlled by the sedimentary facies and different sedimentary condition, the remaining oil in thin layers distribute with a lot of diversity (TABLE 2). Layers of S74—S73-2 were divided as root fan, which means sand body joined together and distributed as "extensive connecting sand body", and the lateral and vertical anisotropy of the reservoirs were quite weak, with quite good sand connectivity, and high producing degree, quite good reservoir property, and quite strong water flooded condition. And thin layer of S6 were divided as edge fan, whose ran off channels had small scale and relatively higher mud content, and they were mostly evaluated as dry layers or poor reservoirs, and not the main target of the later potential tapping. Layers of S73-1—S71 were divided as mid fan, which were mainly multi- stage braided channel sediments and fine flooding sediments. And the channels superimposed, and laterally cut by each other, meanwhile the sand bars inside the channels deposited adjacent to channel, which means architectural interface with a shielding effect [13]. The mid fan reservoirs have lower producing degree, and relative enriched remaining oil, and are the direction of later potential tapping.

Through comprehensive analysis of drilling and production data, and synthesized study on water flooding condition from regular and exceptional logging, production performance data, and inter- confirmation of various data, it was concluded that the remaining oil distribution of Kexia formation reservoirs in Liuzhongdong area were controlled by factors as follows: sedimentary micro facies, seepage difference inside the reservoirs, sand body controlling degree under recent well pattern, and development technique and strategy. And the occurrence state of remaining oil has several types as follows: non-correspondence between injection and production, top oil layers, interface shielding, and sand lens. The distribution types are bound with the sedimentary facies: the inner (S74) and outer (S73-3-S73-2) belt of root fan of Kexia conglomerate reservoirs have better extension, and quite strong water flooding, and the remaining oil are mostly non-correspondence between injection and production type, and top oil layers type as well; and the mid fan (S73-2-S71) has moderate extension, quite strong heterogeneity, and the remaining oil are mostly top oil layers type, and interface shielding type as well; and the edge fan (S6) has small scale sand bodies, and relative poor reservoirs, and the remaining oil are mostly lens.

5 Conclusions

The reservoirs in Liuzhongdong area in Xinjiang oilfield have quite strong anisotropy both in the plane and vertical direction. And the injected water fingering within the layers with better permeability in production, the thin layers have obvious water flooding grades. The strong flooded layers are mainly in S74 and S73-3, which are in the lower section of Kexia formation. And from S74 to S73-1, the percentage of moderate flooded and strong flooded gradually decreases, and to the "extensive connecting sand body", the remaining oil of upper layers S73-1 and S71, are relatively more enriched. And the occurrence state of remaining oil has several types as follows: non- correspondence between injection and production, top oil layers, interface shielding, and sand lens. The mid fan reservoirs are interlayers of multi- stage braided channels and flooding fine sediments, and the channels superimposed and laterally cut by each other, which lead to reservoir anisotropy. And its remaining oil models are mostly top oil layers type, and interface shielding type as well. And the mid fan has lower producing degree and enriched remaining oil, which means the main direction of the later potential tapping. Based on the remaining oil distribution model, the deep flooding plan of secondary development in Liuzhongdong area in Xinjiang oilfield was formulated, and obtained a good result.

TABLE 2 Property and water flooding characteristics of reservoirs of different sedimentary facies

layer	Subfacies	Microfacies	Architecture elements	Average porosity %	Average permeability ×10-3μm2	Water Flooding grade	Oil saturation %	Remaining oil potential
S74	inner belt of root fan	Trench flow	Trench flow conglomerate, Trench flooding sandy conglomerate	18.0	258.6	Moderate, strong flooded	64.6	Strong water flooding, relative less remaining oil
S733	outer belt of root fan	Lamellar flow	Lamellar flow conglomerate	18.5	436.7	Moderate, strong flooded	65.7	
S732				19.7	808.8	Moderate, weak flooded	66.3	
S731	Mid fan	Braider flow	Braided channel, Braided sandy conglomerate bar	20.0	653.4	Weak, moderate flooded, oil	67.3	Remaining oil enrichment
S723				20.7	1016.2	Weak flooded, oil, moderate flooded	69.9	
S722				19.9	494.2	Weak, moderate flooded, oil	69.0	
S721				20.4	366.9	Weak flooded, oil	69.6	
S71		Sheet flood flow	Sheet flood sand	19.8	380.3	Oil, weak flooded	67.5	
S6	Edge fan	Runoff	Runoff channel	19.3	230.0	moderate, strong flooded	65.3	Poor reservoir, not the main potential

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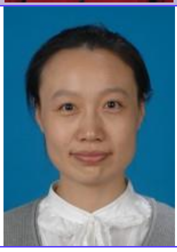

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