IOSR Journal of Engineering (IOSRJEN) **www.iosrjen.org**
ISSN (e): 2250-3021, ISSN (p): 2278-8719
Vol. 06, Issue 04 (April. 2016), ||V1|| PP 53-58

Distribution of the microscopic remaining oil of channel sand reservoir and its influenc factors

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Abstract: Channel sand reservoir is of great thickness and has good physical properties and hydrocarbon enrichment. However, due to the strong heterogeneity of the reservoir, the distribution of oil and water is very uneven after the long-term water flooding development. Hence studies on the emplacement conformation and origination of this of oil are of great importance to stable production of oil field.The article takes distributary channel of delta distributary plain of Pu-I Group in Xingnan oilfield and combines with thin section, electron microscope and mercury injection data to study in detail microscopic pore structure characteristics of the channel sand and to divide the microscopic pore structure types. Based on the above researches, the morphology and distribution of the remaining oil in different types of pore structure in distributary channel reservoir layer have been studied, and the influence factors of remaining oil distribution have been discussed. The results show that the remaining oil mainly presents network, clusterin the early development of the water flooding, presents plaque, isolated droplets, attachment and oil-water mixed phasesin the late development stage. The main influence factors of remaining oil are the wettability of rock surface and Microscopic Pore Structure, content of interstitial material and oil-water viscosity ratio.

Key words: *microscopic remaining oil; channel sandbody; pore Structure*

In the oil field of Cenozoic petroliferous basins which have developed in the eastern China, oil reserves of fluvial reservoir account for more than 40%. In the process of oilfield water flooding development, except remaining oil of unswept water flooding , the large number of remaining oil remains in water flooding and microscopic pores in the region, according to study of the former Soviet Union experts showing that. This part of the remaining oil exist most in the form of thin film, small liquid droplets of being held up in the large pore or micropore, about accounting for about 38% of the total remaining oil, therefore the researches of distribution of microscopic remaining oil and its influencing factors has important theoretical and practical significance.
Predecessor made a lot of work in the distribution of remaining oil and potential tapping, mainly carrying on the elaboration from macro and micro distribution of remaining oil. The remaining oil macroscopically is controlled in sedimentary facies types, but in the interior of same sedimentary facies, macroscopic remaining oil is mainly affected by reservoir heterogeneity, reservoir heterogeneity differences essentially is due to the difference of microcosmic pore structure of reservoir, the present work mostly centered on the reservoir characteristics and the distribution of macroscopic and microscopic remaining oil in the block of a study, but the researches of the distribution of microscopic remaining oil of a certain sedimentary microfacies types and its contributing factors are lacking, which is unable to meet the fine reservoir description. This paper makes the use of the data of mercury injection,thin section, cast thin section, scanning electron microscope and fluorescence thin section data and then studies distributary channel in detail in Xingnan oilfield, puts forward the distribution of remaining oil in distributary channel microfacies and shape,which has important significance in the pertinence of potential excavation of remaining oil.
Xingnan oilfield is located in the HagakiAkioka structure of South Daqing. Its oil-bearing area is 159.5km^2, geological reserves is 5556×10^{4}t. Xingnan reservoir, a total of 4 reservoirs (Sa Ⅱ group, Sa three group, Pu-I group and PuⅡgroup), 13 sandstones groups, 42 small layers. Among them, Pu I 2 - 3 small layer belongs to the distributary plain facies of shallow water delta, distributary channel developing extremely.

I. THE TYPES OF PORE STRUCTURE AND THE DISTRIBUTION OF REMAINING OIL

1.1 Types of pore structure and its characteristics
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1.1 Types of pore structure and characteristics
(1) The mineral composition of channel reservoir in the research area of characteristics of skeleton is mainly feldspar and quartz, including igneous rock, metamorphic rock and sedimentary rock cuttings. Among them, the content of feldspar detritus is the highest, accounting for 34% to 46% of the total; the content of quartz takes second place, accounting for 26% of the total to 40%; in clastic rocks the content of volcano rock cuttings is the

highest, about 10% ~ 26%, 2% ~ 6% metamorphic rocks, sedimentary rocks from 1% to 11%.
In particle size, 70% particle between 0.15 ~ 0.25mm, which belongs to the fine sand level. Sorting is medium, psephicity is subangular.
The inter particle fillings in the main mineral components are: quartz, feldspar, calcite, dolomite, kaolinite, illite, pyrite, magnesite, etc. In the middle and upper part of the river channel, kaolinite and illite are numerous, in the lower part, quartz, feldspar, kaolinite and illite are more than others.

(2) The characteristics of f fluid flow through porous medium

Permeability distributes between the $10 \times 10^{-3} \sim 2\ 000 \times 10^{-3}\ \mu m^2$, mainly belonging to the reservoirs with high permeability and porosity distributes between 17% to 33%, mainly belong to high porosity reservoir. Among them, permeability of the river channel in the middle and upper part is most below $500 \times 10^{-3}\ m^2$, the permeability of bottom river channel is most more than $500 \times 10^{-3}\ m^2$.
Effective seepage channel radius is between 0.63 ~ 63 μ m and the peak value is between 2.5 and 16 μ m. Mainly oil delivery pore radius is from 10 to 63 μ m and the peak value is from 10 to 16 μ m. The upper channel effective flow channel radius is from 1.6 to 10μm, the middle is from 2.5 to 16 μm, the lower part is 4 ~ 25 μm.

(3) The pore throat network characteristics

According to the type and content of the authigenic minerals in sandstone, bed of interest in the study area should belong to the B phase of early diagenesis stage, which is mainly composed of primary intergranular pores, and a small amount of secondary corrosion pores. The pore radius is mainly between 30 and 50 μm, throat radius is between 3 ~ 6 μm. Pore throat ratio is between 3 and 9.

Table 1 Pore conflguration types in distributary channel reservoirs

type	Ⅰ	Ⅱ	Ⅲ	Ⅳ
permeability /$10^{-3}\mu m^2$	>1000	500-1000	50-500	10-50
porosity /%	>25	>25	>25	15-25
average of throat /μm	10-14	5-10	3-6	1-3
relative gradation/%	0.98	0.95	0.98	1.44
largest throat radius/μm	51.85	14.73	11.86	8.11
throat radius of mid-value/μm	6.64	3.91	2.71	1.18
plane porosity /%	20.03	21.26	15.54	11.83
displacement pressure /（$kg \times cm^{-2}$）	0.020	0.051	0.066	0.147
mid-value of pressure（$kg \times cm^{-2}$）	0.12	0.21	0.41	5.86
content of interstitial material /%	4.10	4.10	4.82	4.33
largest mercury saturation /%	81.68	80.79	83.71	74.35

(4) Classification of pore structures

A large number of parameters have been obtained by studying the mercury penetration curve, scanning electron microscope, common sheet, cast thin section and so on. It is generally believed that the size, distribution and shape of the throat are the main factors affecting the reservoir permeability. In this paper, the Pu Ⅰ2-3 small layers in the Xingnan oilfield was classified by the pore structure of the skeleton, pore throat size and distribution.

As can be seen from the table 1, the reservoir properties of the pore structure from I to IV are in turn worse. Statistics show that class I pore structure are mainly distributed in the lower part of the river channel, class II pore structure is mainly distributed in the middle and lower part of the river channel, class III pore structure was mainly distributed in the middle and upper parts of the river channel, class IV pore structure are mainly occurred in the middle and upper parts of the river channel. The general trend is in accordance with the characteristics of tapering. There are a few the class Ⅰpore structure in the upper part of the channel, which is located at the center of the channel in the plane.

A sample of distributing in the middle and lower part of the channel in the pore structure is located on the edge of the river channel in the plane. Thus, the reservoir properties depend on the pore structure, and the difference of the pore structure is closely related to the vertical and the plane position in the channel.

1.2 The distribution of remaining oil

According to the distribution of the remaining oil, it can be divided into network, patch, solitary, attached and oil-water mixed phase. Among them, the network refers to the remaining oil in the pore throat network. Plaque refers to larger pore space occupied by residual oil, or in large pores because the velocity of flow is reduced, scour ability is weak, when a channel formed in a continuous aqueous phase, attached near the pore wall of crude oil is not easy to be drive away the water, leading to the formation of plaque of remaining oil.The lone drop is the distribution of remaining oil. Attachment finger is the remaining oil which is attached to particles, because particles with strong adsorptive capacity is not easily waterflooded. The oil-water mixed phase is the area of the coexistence of oil and water in the network.

In the long-term waterflooding process, along with the aggravation of degree of water washing rock matrix, pore network, seepage characteristics and clay mineral content and occurrence of the features are changing. Therefore, the distribution and morphology of remaining oil is changed with it. In different pore structure, the remaining oil content, distribution position and shape are different.

(1) The distribution of residual oil in pore structure

It can be seen from Figure 1, not being washed or low, multi point or point line contact exists among the particles.oil exists in the formations of network, cluster filling in pores among particles (Figure 1a).

a. Unwashed Sample b. Moderate washing Sample c. Strong washinge Sample

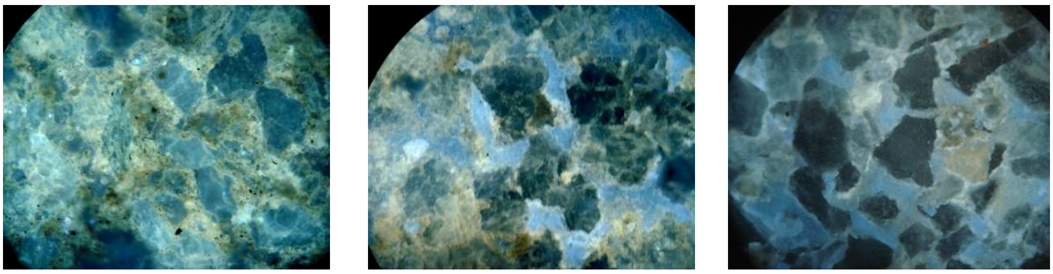
Fig. 1 Residual oil distribution of type 1 pore stucture in different periods

It can be seen from the fluorescence thin, fluorescent color of oil is thick, mainly yellow brown, brown green. Oil immersion phenomenon is visible in the face of rock particles contacting with oil. Low washing, water in large pores existd in little water drop which is oil in water. Fluorescence of water droplets is blue-green. Color of the fluorescence on the surface edge to the particle is from light to dark, which shows that the hydrocarbon accumulation in the particle surface.

As for high water, oil in connected pore throat is replaced by water. Because of the long-term washing, large pores are larger. As shown in Figure 1b, the middle black part is bright in fluorescence thin, which is mainly yellow, yellow green, the chromatic aberration is not strong, reflecting the oil concentration is not high. Because the rock surface changes from oil wet to water wet, there are a few drops of oil stored in the water.The remaining oil mainly is plaque or oil-water miscible form. The darker part of fluorescent color mainly is in the corner, the hole wall and the hole and small pore throat. This part of the remaining oil mainly exists in the form of a drop shaped attachment, solitary. The hole wall dip becomes weak, which is due to the long-term erosion of water, oil film adhered to the hole wall becomes thin. In the view of the pore structure, the small throat around large holes ,small pore throat, oil still remains, reflecting that the water is mainly passing large pore throat and small throat do not play the role of erosion.

(2) The distribution of the remaining oil in the pore structure of class II

Prior to washing oil distributes in the form of network, the cluster in pore throat (Figure 2A). After washing, the distribution of remaining oil becomes uneven (Figure 2B). The general oil in the large part in the smooth pores is washed clean, only a small amount of remaining oil exists in the form of oil-water miscible. Remaining oil distributes in the irregular pore canals,especially position where original particles is the point contact, though the latter term is displacing the water, it forms the unobstructed channels in a relatively narrow channel, when water carried the remaining oil drop passes, often be trapped down forming the formation of plaques and isolated droplets of remaining oil.



a. Unwashed Sample b. Moderate washing Sample c. Strong washinge Sample

Fig. 2 Residual oil distribution of type 2 pore stucture in different periods

(3) The remaining oil distribution characteristics of pore structure of class III

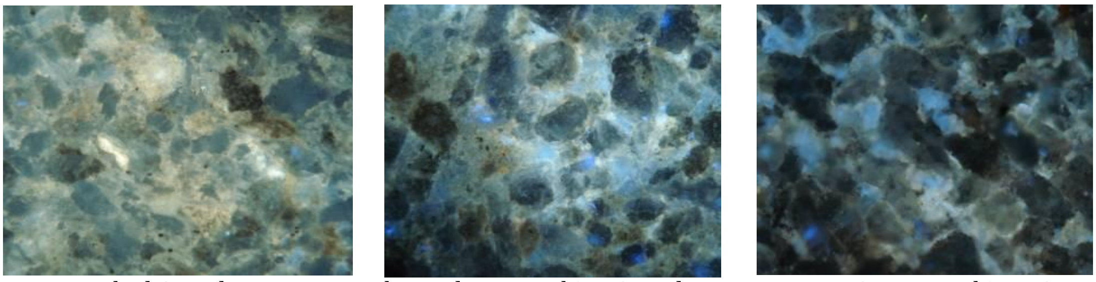
As shown in Figure 3, class III pore fillings are numerous and the pore size is very irregular, oil is filled in the form of network, cluster and intergranular adsorption and other forms of uneven filling in inter particle pores and fillings (Fig. 3a). With the degree of water from weakness to being strong, gradually the remaining oil reduced. In the view of the position, mainly coarse connected pore networks the remaining oil reduced. From Figure 3b, remaining oil on the thick and smooth hole and regular wall has disappeared, the remaining oil in reserve mainly exists in the form of plaque and isolated droplets . There is weak fluorescence in big pore, which shows the surface of hole wall is attached to rare remaining oil film.

a. Unwashed Sample b. Moderate washing Sample c. Strong washinge Sample

Fig. 3 Residual oil distribution of type 3 pore stucture in different periods

(4) The distribution of class Ⅳ remaining oil pore structure

As shown in Figure 4, the pore structure in primary porosity is not developed and the interstitial substance is higher content, before washing oil is dispersed in the form of the secondary dissolution pore. After washing, remaining oil distributes the dispersing isolated droplets, in addition, also filling in fine pore throat, in the form of oil-water phase and attachment.



a. Unwashed Sample b. Moderate washing Sample c. Strong washinge Sample

Fig. 4 Residual oil distribution of type 4 pore stucture in different periods

II. ANALYSIS OF INFLUENCE FACTORS OF THE DISTRIBUTION OF REMAINING OIL

Distribution of remaining oil in micro-pore-throat network is mainly affected by the influence of many factors pore structure, composition and content of fillings, oil-water viscosity and wettability.

2.1 Wettability

As can be seen from the fluorescent sheet, when lower wash the water exists in the form of water in the oil, which can be used to explain the surface of the rock is oil-wetted.For the oil-wetted reservoir, for the first time when water flooding ,water enters the large pore, which is the first that oil isdisplaced. Therefore, the remaining oil is mostly in the form of oil ring and oil film on the pore path of the big pore path wall.While pore path only when the displacement pressure is large enough because capillary force exists, the oil in the small pores path can be displaced. Therefore, the remaining oil in small pore path is also numerous. From the height of the water washed samples, because the large pore path was washed in the long-term strongly, the wettability of the surface of the part of the hole wall translates the pro oil into hydrophilic,this part of the oil ring, the oil film was replaced by oil-water mixture.

2.2 Microscopic Pore Structure

The effect of microscopic pore structure is mainly manifested in the aspects of pore throat size, pore throat morphology, pore throat connectivity and so on.

The greater the pore throat radius is, the better the permeability is, the higher the oil displacement efficiency is, so the remaining oil in the pores is less. The pore throat ratio was negatively correlated with the permeability. That is, the pore throat ratio is high, the permeability is low. Statistical results show that the pore throat ratio is gradually increasing, the permeability is gradually low, and the remaining oil is increased from Ⅰpore structure to Ⅳpore structure.

The pore throat morphology mainly manifested in changes of tortuosity of the throat is more uniform, smooth. Lower tortuosity is, the oil displacement efficiency is higher. conversely, higher tortuosity is, easier it remains in the position where pore throat radius changes so remaining oil increases.

The main performance of the pore throat connectivity is coordination number, and the distribution of the fluid in the micro reservoir has important significance for the distribution of remaining oil. The larger the coordination number is, the better throat and pore connectivity .Oil in the pore is easily driven.

2.3 The effect of fillings

The study area fillings are mainly argillaceous kaolinite, illite, smectite mixed layer, quartz, feldspar, calcite, ankerite, pyrite and magnetite. [11] Filling effects on reservoir mainly include:

(1) The particles migrate out of the reservoir, which can increase the permeability.

Quartz, feldspar, pyrite, magnesite can migrate with water erosion. It can be seen that by casting thin sections, scanning electron microscopy data, before and after washing, the radius of the pore throat has generally increasing trend, the particle surface, especially the large hole wall surface is more smooth, so the porous permeability is better, the remaining oil film is less.

(2) Complete illite bridge was washed away so as to increase the reservoir permeability, and fragments of illite are subsided in the throat and can reduce permeability.

It can be seen from the SEM data, preflood illite can be formed illite bridge, especially in III and IV pore structure. The results can lead to worse reservoir permeability, oil distribution is not continuous. When the degree of water wash increases, it destroyed part of the Erie stone bridge, making local porosity and permeability better, and fragments of illite in the throat of settlement and local permeability decrease.

(3) After washing，kaolinite after water flooding in big pore path is in a disorderly accumulation. In the small pores it is still the like book. Show the large pores mainly affect, small pores basically do not affect.

The relative contents of clay minerals in different pore structure types are different, and the effect is different in the process of washing.

In class I pore structure, clay mineral content generally is lowest, mainly kaolinite and illite mixed layer and illite. Because the pore and throat are large, a small amount of interstitial material with increasing the degree of washing was washed away, the pore surface is cleaner. Porosity and permeability, pore throat radius, face rate were increased.

In class II pore structure, the more content that kaolinite and illite, with the increasing intensity of washing, a part of clay minerals in large pores are washed away and the other part regathered in small pores, to be obstructed by the small pore. Therefore, the porosity and permeability decreases. In the view of from the position of class II and class I pore structure, I class pore permeability is best and locates in the low part of the channel,when water is pouredis the most dominant channel, class II pore structure are mainly in low and middle part.When water is poured the flowing speed in pore is lower than it in the class I pore structure. so the part of the clay minerals is rushed out of the large pore path is easy to be preserved, resulting in reduction of the pore throat radius.

In the pore structure of type III and IV, the select separately is poor. There are a lot of the clay minerals filled, and the pore throat connectivity is poor. But in the effect of long-term washing some bridge structures formed by clay minerals will be destroyed and the debris material can be washed away. So interstitial contents decreased, and porosity and permeability become better, pore throat radius increases ,the surface rate increases.

2.4 Viscosity ratio

When oil water viscosity ratio is high, the oil is easy to stay in the position of the part of the throat. When remaining oil content becomes high, it can add to a higher viscosity of the polymer, so that oil and water viscosity ratio decreases, the water can carry more remaining oil.

III. CONCLUSION

(1) According to the distribution of the parameters such as the skeleton, pore throat size and distribution, the micro pore structure distributary channel reservoirs in the study area are divided into 4 types.

(2) The distribution of remaining oil in different development stages and different pore structure has different characteristics. The form of remaining oil in the early development stage of water flooding is mainly network

and cluster. The form of remaining oil in the and the late development stage is mainly by the shape of patch, solitary drop, attachment and oil-water mixture. From class I to class I V pore structure, the shape of the remaining oil patch and oil-water mixed phase turns into mainly the shape of attachment and solitary drops.

(3) The main factor of the influence of remaining oil is the wettability of the rock surface, micropore structure, interstitial compounds, content and viscosity ratio of oil and water.

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