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Oil Saturation Boundary for Partial Oil and Partial Water Recognition in the Oil-Water Transition Zone

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Abstract

With the development of oilfield, the oil reserves in oil-water transition zone has become a significant part of comprehensive reserves gradually. Especially the partial oil layer of oil-water transition zone has potential exploitation. But how to identify partial oil layer has become a difficulty in the development planning of the oil-water transition zone. Over the years, there has been little research on the oil-water transition. The oil saturation boundaries for partial oil and partial water recognition are mainly studied in this paper. Two major approaches, theoretical calculation methods and cumulative probability curve have been applied to the study. That will provide the basis for further perforation development and dynamic adjustment.

Key words: The oil-water transition zone; Partial oil layer; Oil saturation; Theoretical calculation methods; Cumulative probability curve

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INTRODUCTION

With the deepening of development work, Majority of Chinese eastern oilfields have entered high or extra-high water-cut stage. Production is decreasing at an accelerating rate and the remaining recoverable reserves are declining because of the rising water content[1,2]. In order to meet sustained production of oilfields, many oilfields are exploring the oil-water transition zone between pure oil formation and pure water formation gradually along with technical level rising. With commercial exploitation value, the oil-water transition zone where oil and water exist and produce at the same time, is mainly partial oil layer[3.4]. For the above reasons, the principal job for exploiting oil-water transition zone is to distinguish the position of the partial oil layer, which helps lay a foundation for shooting and exploitation.

Recognition methods for partial oil and partial water of oil-water transition zone are as follows: the judgement is based on the characteristics of logging curves in the objective layers[5]; analyze coring well, well testing data and logging response to draw up logging interpretation chart[6]; apply S_w—S_{wi} cross plot[7] and so on. This paper mainly studies the oil saturation boundary of partial oil layer that has potential capacity of exploitation. Based on distinguishing the oil-water transition zone, apply computational method theoretically and cumulative-probability plot to determine oil saturation boundary

1. THEORETICAL CALCULATION METHODS

On the basis of fractional flow equation and Jones empirical formula, computation formula about water saturation S_w can be derived and then oil saturation S_o can be calculated[8].

$$S_o = 1 - S_w = 1 - \frac{(1-S_{wi})(1-S_{or}) + \sqrt[3]{\left|\frac{1}{F_w}-1\right| \bullet \frac{\mu_o}{\mu_w}}(1-S_{wi}-S_{or})S_{wi}}{\sqrt[3]{\left|\frac{1}{F_w}-1\right| \bullet \frac{\mu_o}{\mu_w}}(1-S_{wi}-S_{or}) + (1-S_{wi})} \quad (1)$$

As shown: μ_o——oil viscosity, (MPa·s);
μ_w——water viscosity, (MPa·s);

F_w——water production rate, %;
S_w——water saturation, %;
S_{wi}——irreducible water saturation, %;
S_{or}——residual oil saturation, %.

Apply theoretical methods and also refer to 98% water ratio as upper limit when calculate recoverable reserves[9,10]. According to formula (1) calculation, oil saturation is 41% as a reference value of oil saturation's lower limit in the partial oil layer of oil-water transition zone.

Based on the analysis of water content condition of the Saertu development zone in September 2011 where water flooding and polymer flooding were used, the water saturation in the water flooding block after polymer flooding is higher ranging from 94.39% to 97.2%; the highest water saturation of different well patterns in the water flooding blocks is 94.99%. According to water content conditions of different well patterns, the water ratio's upper limit in the partial oil layer of oil-water transition zone is determined as 96.65%, which is average value of the block where water flooding is carried out after polymer flooding.

The sampling depth of the well Nan A located in oil-water transition zone is from 1177.3 to 1178.3 meters. According to the relative permeability curve data of three samples and formula (1) calculation, the results are as follows (Table 1, Table 2). When water ratio is 96.47%, 96.87% and 96.89% respectively, the average value of water saturation is 58% and then oil saturation limit is determined as 42% accordingly.

Table 1
The Relationship Between Water Saturation and Water Ratio in the PI2-3 Layers of Well Nan A

S_w	K_{ro}	K_{rw}	F_w(%)
0.301	1	0.001	0.81
0.325	0.905	0.01	8.31
0.35	0.785	0.015	13.55
0.375	0.67	0.023	21.97
0.4	0.565	0.03	30.33
0.425	0.47	0.035	37.91
0.45	0.365	0.04	47.33
0.475	0.27	0.046	58.28
0.5	0.195	0.054	69.43
0.525	0.13	0.061	79.37
0.55	0.08	0.07	87.77
0.575	0.05	0.08	92.92
0.6	0.025	0.095	96.89
0.625	0.01	0.11	98.90
0.65	0.004	0.126	99.61
0.675	0.003	0.147	99.75
0.7	0.002	0.17	99.86
0.725	0.001	0.2	99.94
0.764	0	0.245	100.00

Table 2
The Relationship Between Oil Saturation and Water Ratio in the PI2-3 Layers of Well Nan A

Sample depth (m)	S_w	S_w (AVG)	K_{ro}	K_{rw}	F_w (%)	S_o	S_o (AVG)
1178.3	0.60		0.03	0.10	96.89	0.40	
	0.61				98.0	0.39	
1178.2	0.58	0.58	0.02	0.08	96.87	0.43	0.42
	0.59				98.0	0.41	
1177.3	0.55		0.03	0.10	96.47	0.45	
	0.57				98.0	0.43	

2. CUMULATIVE PROBABILITY CURVE

By the study on relationship among lithology, physical properties, oiliness and electrical property in the oil-water transition zone, we can find that the partial oil layer of oil-water transition zone has higher permeability. Its amplitude of SP is lower and the amplitude of resistivity curve is higher. What is more, oiliness is better, namely oil saturation is higher. But the partial water layer is adverse[11]. It can be seen, it will be a good way to make a distinction between partial water layer and partial oil layer by oil saturation boundary.The systematic sense of cumulative-probability plot is: the more similar geologic feature and parameter value are, the greater the slope of straight line at that point is. On the contrary, the slope is lower. Therefore, the parameters with different distribution characteristics can form different slope of the straight line which reflects the different reservoir properties. So the oil saturation of oil-water transition zone can be described as a cumulative-probability plot. The straight line of different slope can determine the oil saturation boundary of partial oil layer and partial water layer in the oil-water transition zone[12] (Figure 1).

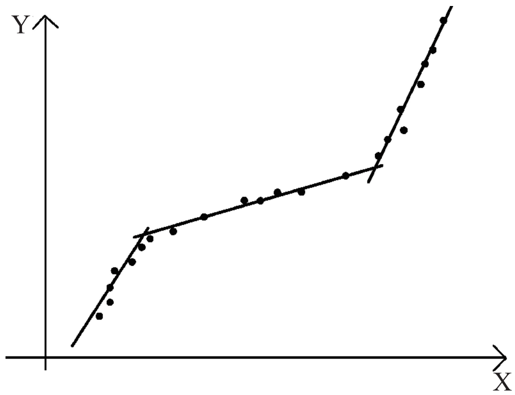

Figure 1
Cumulative-Probability Plot

All oil saturation from sample points of sealed coring well in the oil-water transition zone can be mapped into cumulative-probability plot (Figure 2). The figure shows that when oil saturation is less than 42%, it will be judged as partial water layer. The higher the oil saturation is, the lower the mining value is. When the oil saturation is higher than 42% and the water saturation is less than 58%, it will be the partial oil layer with high production value.

Divide layer in the light of the data from all sample points in the oil-water transition zone. Many oil saturations from the same small layer will be weighted average, so every small layer has an average of oil saturations. The cumulative-probability plot will be described by the obtained data. The results are shown in Figure 3. The oil saturations boundary is 40 percent. In other words, it's partial oil layer if oil saturations higher than it and the value of mining is high.

Considering the above two results and the practical application of oilfield, the oil saturation limit is set at 40%.

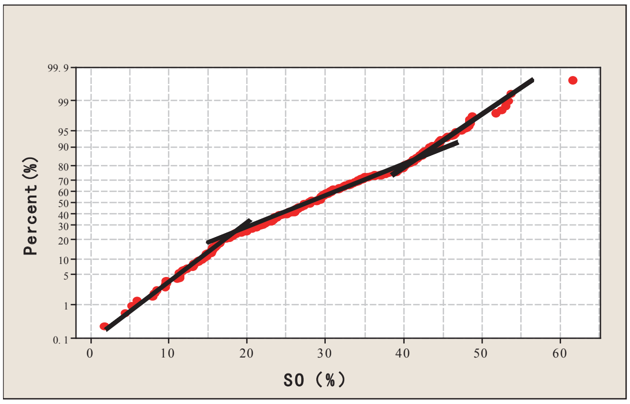

Figure 2
Probability Graph About Oil Saturation of All Sample Points

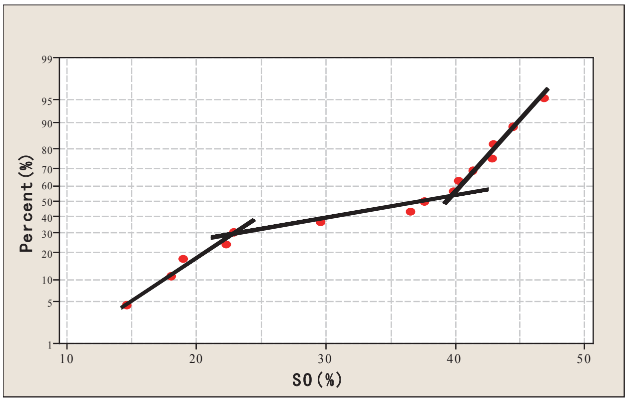

Figure 3
Probability Graph About Oil Saturation of All Small Layers

3. APPLICATION

There are three testing wells in this area. Apply well testing data from eight small layers of three wells in the oil-water transition zone to verify. The three wells are well Gao 1, well Nan 1 and well Nan 2. Finally, Comprehensive factors determine the oil saturation of 40% is the boundary of partial oil layer and partial water layer. The verification results suggest that seven of the eight small layers conclusions are consistent. Therefore, accurate rate is 87.5%. Detailed results are as follows (Table 3).

Table 3
Oil-Water Transition Zone Test Results Inspection Table

Well name	Layer	Top (m)	Bottom (m)	Effective thickness(m)	Daily oil production (t)	F_w (%)	Well testing conclusion	S_o (%)	Application conclusion	Final conclusion
Gao 1	1	1187	1189.1	2.1	0.039	46.5	low yield water/ oil layer	40.5	partial oil	agreement
Gao 1	2	1192	1193.2	1.2	1.283	0.0	low yield commercial oil reservoir	52.1	partial oil	agreement
Gao 1	3	1195.7	1198.3	2.6	0.517	22.1	low yield water/ oil layer	56.8	partial oil	agreement

To be continued

Continued

Well name	Layer	Top (m)	Bottom (m)	Effective thickness(m)	Daily oil production (t)	F_w (%)	Well testing conclusion	S_o (%)	Application conclusion	Final conclusion
Gao 1	4	1205.4	1207.6	2.2		100.0	water layer	31.4	partial water	agreement
Nan 1	1	1185.3	1186.4	1.1	1.654	2.4	low yield commercial oil reservoir	45.3	partial oil	agreement
Nan 1	2	1195	1196.8	1.8	0.464	4.1	low yield water/ oil layer	40.3	partial oil	agreement
Nan 2	1	1196.6	1198	1.4	1.04	8.8	low yield commercial oil reservoir	42.6	partial oil	agreement
Nan 2	2	1211.8	1213	1.2	0.261	38.3	low yield water/ oil layer	29.4	partial water	disagreement

CONCLUSION

(1) On the basis of the relative permeability data of coring well, apply theoretical computational method to obtain average of water saturation in the oil-water transition zone which is 58% and oil saturation limit which is 42%.

(2) Taking cumulative probability curve into application, oil saturation limit in the oil-water transition zone is 40%.

(3) Not only synthesize two methods above, but also consider the present situation of oilfields. Finally the oil saturations lower limit in the partial oil layer of oil-water transition zone is set at 40%.

(4) Well testing data is applied in validating the conclusions of the research. The accurate rate is 87.5%. The conclusion shows that the above-mentioned methods accord with the present exploitation situation of oilfield and it's necessarily available in the partial oil and partial water recognition of oil-water transition zone, which has a certain guiding significance for adjustment measures to implement.

REFERENCES

[1] Fang, H. C., & Feng, M. S. (1999). Direction in Enhancing Waterflooding Recovery of Oil Fields with High Water-Cut in Eastern China. *Petroleum Exploration and Development*, *26*(1), 40-42.

[2] Lu, R. J., & Zhang, S. W. (2011). Widen Old Oilfield Sustained Production. *China Petrochem*, (4), 57-61.

[3] Liu, W. (2008). The Potential Analysis of Oil and Water Layer. *Petroleum Geology & Oilfield Development in Daqing*, *27*(6), 80-82.

[4] You, L. L. (2012). Potential Research of Oil and Water Layer in the Area A Transition Zone. *Science and Technology Innovation Herald*, (21), 96.

[5] Mu, C. H., Liang, X. L., & Ma, L. M. (2006). Oil-Water Mixed Layer Logging Interpretation Method in Sabei Development Area. *Petroleum Geology & Oilfield Development in Daqing*, *25*(6), 112-115.

[6] Guo, S. M., & Wang, Q. J. (2006). Study on Interpretation Criteria for Oil-Water Bearing Zones and Reservoir Parameters. *Petroleum Geology & Oilfield Development in Daqing*, *25*, 27-28

[7] Han, X. (2009). A Method to Identify Complex Oil and Water Coexistence Reservoirs with Low Porosity and Permeability. *Sino-Global Energy*, *14*(5), 61-63

[8] Ding, X. Q., & Zhang, S. N. (2007). Apply Water/Oil Relative Permeability in Analyzing Fluid Production of Chang-6 Reservoir in the Zhenjing Oilfield. *Computing Techniques for Geophysical and Geochemical Exploration*, *29*(5), 411-414.

[9] Chen, Y. Q., & Guo, E. P. (2007). A Method to Predict Volumetric Sweep Efficiency and Recoverable Reserves of Water-Drive Oilfields. *China Offshore Oil and Gas*, *19*(6), 387-389.

[10] Tao, Z. Q., & Tian, X. X. (2004). Research on How to Select Water Ratio Limit of Water Drive Curve. *Tianjin Science and Technology*, *4*, 14-15.

[11] Guo, D. C. (2010). *Research on Developing Limits of Oil-Water Transition Section in Sabei Development Area* (pp. 9-22). Daqing: Northeast Petroleum University.

[12] Fan, T. L., & Fan, Y. X. (2010). Contrast Frequency Distribution Curve and Cumulative Probability Curve Apply in the Grain Structure Analysis of the Deposit. *Gansu Geology*, *19*(2), 32-38.

