Quantitative reservoir classification and evaluation based on reservoir microscopic characteristics

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Abstract. In view of the remaining oil recovery situation and the needs of the development of tertiary oil recovery technology, using mercury intrusion data, through statistical analysis of the relationship between microscopic pore structure parameters and permeability, it is clear that there is a good correlation between permeability and various microscopic pore structure parameters. It is believed that the reservoir permeability can comprehensively and quantitatively characterize the complexity of the pore structure of the reservoir. The higher the permeability, the weaker the microscopic heterogeneity of the reservoir and the better the reservoir quality. And according to the microscopic characteristics of the reservoir, it is quantitatively divided into Type I reservoir, Type II reservoir, Type III reservoir, Type IV reservoir and Type V reservoir, which realizes the quantitative classification and evaluation of complex reservoirs, which is the best reservoir for reservoirs. The deepening understanding of strata has laid a foundation for the selection of tertiary oil recovery injectors.

Keywords: Permeability, pore structure, reservoir division

1. Introduction

After nearly 50 years of development, the comprehensive water cut of A oilfield has reached more than 93%, and it has been in the development stage of ultra-high water cut stage. After long-term development, the remaining oil in the oil layer is highly dispersed and complicated in spatial distribution mode, and the remaining oil coexists with inefficient and ineffective circulation layers, which makes the mining difficulty gradually increase. Practice shows that the characteristics of reservoir micro-pore structure are closely related to the characteristics of oil-water distribution, and the research depth of reservoir rock micro-pore structure affects the accuracy of understanding the distribution law of oil (gas) and water to a certain extent. At the same time, with the development of tertiary oil recovery technology and the concept of molecular dynamic radius, the quantitative evaluation of reservoirs has clear requirements. Therefore, it is very necessary to quantitatively refine reservoir categories and evaluate them by using reservoir microscopic characteristics. In this paper, the relationship between microscopic pore structure parameters and permeability is statistically analyzed, the quantitative classification method of microscopic pore structure of reservoir is explored, and various core data are analyzed, so as to realize the quantitative classification and evaluation of complex reservoirs, provide the basis for polymer optimization and provide strong support for the exploitation of remaining oil.

2. The Microscopic Significance of Reservoir Permeability

The characteristics of reservoir micro pore structure refer to the geometry, size, distribution and interconnection of pores and throats in rocks [1]. Its research content is an important content of fine reservoir description and comprehensive reservoir evaluation. It is the key to the effective development of oil and gas reservoirs, and determines the formulation of reservoir reconstruction technology and development technology policy [2-3]. In the process of oil and gas field development, the pore structure of reservoir rock is the main factor affecting the reservoir fluid storage capacity and oil and gas production [4-5]. At present, various parameters representing reservoir pore structure are mainly measured in the laboratory. Permeability is an easily obtained and widely used physical parameter, which indicates the permeability of rock. By establishing the scatter diagram of the corresponding relationship between permeability and reservoir micro parameters, explore the internal relationship between them, so as to determine whether it is feasible to characterize reservoir micro characteristics with permeability.

By analyzing the microscopic pore structure parameters of A Oilfield, it is found that among the 14 microscopic pore structure parameters, 11 parameters (maximum pore throat radius, relative sorting coefficient, characteristic structure parameters, etc., see Table 1) representing the pore throat size, distribution and connectivity characteristics of reservoir are highly correlated with permeability. That is, different permeability represents different reservoir microscopic characteristics, and the characteristics of reservoir microscopic pore structure change with the change of permeability.

Table 1 Statistical table of correlation between reservoir permeability and microscopic pore structure parameters

Microscopic Pore Structure Parameters (X)	Relationship with permeability (Y)	Relationship type	Correlation coefficient
Maximum pore throat radius (μm)	y = 0.8713x2.3366	Exponentiation	0.893
Average pore throat radius (μm)	y = 14.841x1.9364	Exponentiation	0.944
Median pore throat radius (μm)	y = 108.87x1.1407	Exponentiation	0.925
Average radius (μm)	y = 30.333x1.7412	Exponentiation	0.956
Displacement pressure (MPa)	y = 0.4888x-2.2985	Exponentiation	0.890
Median pressure (MPa)	y = 71.306x-1.1545	Exponentiation	0.931
Sorting factor	y = -629.62x + 3169.2	linear	0.309
Relative sorting coefficient	y = 249.12x-1.7773	Exponentiation	0.958
Skewness	y = 15.391e5.2828x	index	0.823
Homogeneity Coefficient	y=8325.9x5.3204	Exponentiation	0.863
Structural factor	y = 547.87e-0.2578x	Index	0.258
Feature Structure Parameters	y = 912.88x1.5349	Exponentiation	0.913
Maximum mercury saturation (%)	y = 0.0013e0.1415x	Index	0.628
Maximum exit efficiency (%)	y = 6E+07x-4.7473	Exponentiation	0.902

3. Quantitative Reservoir Classification and Evaluation

3.1 According to the standards of petroleum industry, the micro pore structure category is proposed

From the above analysis, it can be concluded that most of the pore structure parameters have a good correlation with permeability, that is, when the permeability is similar, the reservoir pore structure is similar. Therefore, reservoir pore structure can be classified according to the permeability. According to the petroleum industry standard of Sinopec, the pore structure types of reservoirs in Xingbei area are classified into five categories (Table 2).

Table 2 Permeability Grading Standard Table (SY/T6285-1997)

Permeability(mD)	Penetration rating	Pore Structure Type
K≥2000	Hypertonic	Class I
500≤K＜2000	Hypertonic	Class II
50≤K＜500	Medium penetration	Class III
10≤K＜50	Hypotonic	Class IV
1≤K＜10	Ultra-low osmotic	Class V
0.1≤K＜1	Ultra-hypotonic	
K＜0.1	Non-permeable	

3.2 Statistics of permeability distribution characteristics and subdivision of pore structure types in xingliudong

It can be seen from the coring wells that the average pore radius, median pore radius, relative sorting coefficient, characteristic structural parameters and displacement pressure are all quite different in the reservoirs with Class III pore structure with permeability of 500-50mD and Class II pore structure with permeability of 500-2000mD (Table 3). Although it is the same pore structure, its microscopic characteristics are quite different, so it is necessary to further subdivide the category of reservoir microscopic pore structure. Therefore, it is attempted to further subdivide the category of pore structure in high permeability reservoirs with permeability of 2000-500mD and medium permeability reservoirs with permeability of 500-50mD.

Table 3 List of microscopic pore structure parameters corresponding to different permeability

Category	Rock sample number	Air permeability (10-3μm2)	Average pore radius(um)	Median pore radius(um)	Relative sorting coefficient	Characteristic structure parameters	Displacement pressure (MPa)
Class II	205	90.50	2.715	0.741	2.185	0.174	0.096
	95	181.00	3.688	1.038	1.275	0.315	0.069
	120	273.00	4.471	2.153	1.099	0.343	0.069
	155	332.00	5.436	5.672	0.594	0.596	0.048
	75	479.00	6.050	6.869	0.554	0.650	0.048
Class III	35	877.00	7.670	7.944	0.468	0.821	0.034
	230	1485.00	10.455	10.797	0.385	0.983	0.027
	165	1813.00	11.595	12.963	0.271	1.385	0.027

From the shape of the mercury intrusion curve (Figure 1), the mercury intrusion curves in different permeability ranges have different manifestations, that is, they have different microscopic pore structure characteristics. And the type II pore structure is further subdivided.

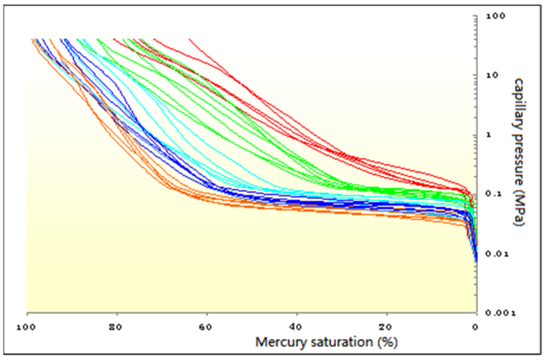


Fig. 3 Morphological distribution of mercury intrusion curves at different permeability levels

In conclusion, in order to better reflect the reservoir micro pore structure in Xingbei area, on the basis of the standard classification of Sinopec petroleum industry and combined with the characteristics of mercury injection curve, class II A and class II B are finely divided in class II pore structure, and class III A, class III B, class III C, class I, class IV and class V remain unchanged in class III pore structure. From the macro aspect, the reservoir can be quantitatively divided into 5 categories and 8 sub categories according to the micro characteristics. After subdivision, the micro characteristic parameters (pore throat radius, relative sorting coefficient, characteristic structure coefficient, etc.) of different types of reservoirs are obviously different and regular, reflecting the rationality of classification (Table 4).

Table 4 List of pore structure classifications in Xingbei area

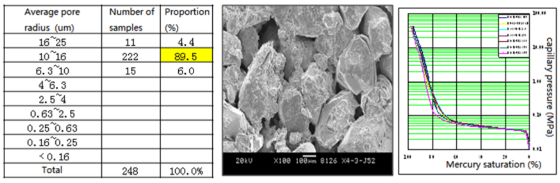
Parameter type	Pore structure parameters	Class I	Class II		Class III			Class IV	Class V
			A	B	A	B	C		
Physical properties	Permeability(10-3μm2)	≥2000	1000-2000	500-1000	300-500	100-300	50-100	10-50	<10
		3325.2	1414.4	728.5	382.3	189.5	73.9	25.1	3.8
Pore throat shape size	Maximum throat radius(μm)	27.98	22.66	18.20	13.92	11.48	8.09	6.09	3.45
	Average pore throat radius(μm)	13.78	10.28	7.70	5.86	4.31	2.64	1.79	0.79
	Median radius of hole throat(μm)	14.61	9.31	6.39	4.38	1.31	0.58	0.41	0.18
	Mean radius of flow hole throat(μm)	12.59	8.75	6.45	4.78	2.99	1.74	1.16	0.50
Pore throat Distribution	Relative sorting coefficient	0.24	0.39	0.54	0.80	1.45	3.07	4.19	11.10
	Homogeneity coefficient	0.50	0.46	0.44	0.44	0.38	0.32	0.27	0.22
Pore throat Connectivity	Characteristic structure coefficient	2.27	1.09	0.75	0.46	0.25	0.23	0.13	0.06
	Structural coefficient	2.17	2.81	2.98	3.11	3.29	3.51	3.60	4.06

3.3 Evaluation of microscopic pore structure characteristics of different types of reservoirs

On the basis of reservoir classification, combined with mercury intrusion curve, scanning electron microscope, particle size analysis and other data, the microscopic characteristics of various reservoirs are summarized.

3.3.1 Microscopic characteristics of class I reservoir

Class I reservoir is mainly composed of medium sand, fine sand and the grain size between them, with medium dense grain arrangement; Roundness is mainly secondary circle and secondary edge, cementation types are mainly pore cementation and film-pore cementation, and contact relationship is mainly point-line contact. Pores in this type of reservoir are well developed, and the pore types are mainly intergranular pores. Porosity is 25-32%, with an average of 28.73%, permeability of 3119.64mD, pore throat radius of 6.3-25μm, pore diameter of 10-16μm, displacement pressure of 0.02MPa and maximum mercury saturation of 94.25%. From the characteristics of capillary pressure curve, the reservoir has a long platform section, with concentrated pore throat distribution, well-selected pores and large pore throat radius. This type of reservoir has the best pore structure characteristics and the best reservoir quality (Figure 2).

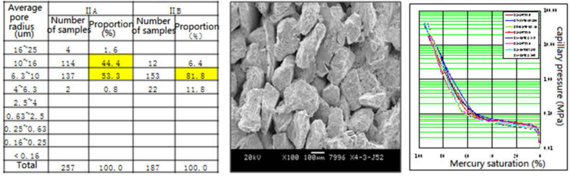


Average pore radius (um)	Number of samples	Proportion (%)
16~25	11	4.4
10~16	222	89.5
6.3~10	15	6.0
4~6.3		
2.5~4		
0.63~2.5		
0.25~0.63		
0.16~0.25		
<0.16		
Total	248	100.0%

Fig. 2 Type I pore structure characteristics

3.3.2 Microscopic characteristics of type II reservoirs

The grain size of Type II reservoirs is mainly fine sand, the grains are closely arranged, some grains are inlaid, the pores are relatively good, and the connectivity is good; the roundness is mainly sub-circle and sub-edge, and the cementation type is mainly pores Cementation, film cementation, contact cementation and transition cementation of the three, the contact relationship is mainly point contact; the porosity is between 19-32%, the average is 27.95%, the average permeability is 1050.78mD, and the pore throat radius is mainly distributed in 4 -25μm range, and the pore size is mainly 6.3-16μm, the average displacement pressure is 0.03MPa, and the maximum mercury saturation is 89.50% on average; from the characteristics of the capillary pressure curve, the reservoir has an obvious platform section, and the reservoir pores The throat distribution is relatively concentrated, the sorting is moderately preferred, and the microscopic heterogeneity of the reservoir is relatively weak, among which the pore structure gradually deteriorates from IIA to IIB. This type of reservoir has a well-developed pore structure and is a medium-high porosity and high permeability reservoir (Figure 3).

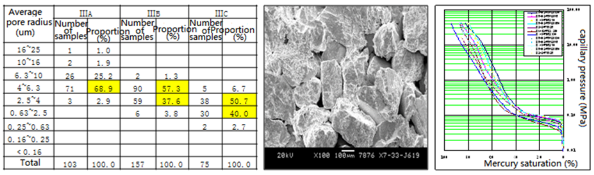


Average pore radius (um)	IIA		IIB	
	Number of samples	Proportion (%)	Number of samples	Proportion (%)
16~25	4	1.6		
10~16	114	44.4	12	6.4
6.3~10	137	53.3	153	81.8
4~6.3	2	0.8	22	11.8
2.5~4				
0.63~2.5				
0.25~0.63				
0.16~0.25				
<0.16				
Total	257	100.0	187	100.0

Fig. 3 Type II pore structure characteristics

3.3.3 Microscopic characteristics of class III reservoir

The reservoir is fine sand, the grain size is relatively small, the reservoir is generally fine sand, and the pore is generally connected, and the part is fine sand; The roundness is mainly sub round, and the cementation types are mainly pore cementation, film cementation and pore film cementation. The contact relationship is mainly point contact and some are point line contact; The porosity is 14-32%, the average is 25.83%, the average permeability is 210.52md, and the pore throat radius is mainly distributed in 0.25-25 μ M range and 0.63-6.3 μ M, the average drainage pressure is 0.08mpa, and the average maximum mercury saturation is 81.45%; From the characteristics of capillary pressure curve, the reservoir has a short platform section, the distribution of pore throat is not concentrated, the sorting is poor, and the micro heterogeneity of the reservoir is strong. Among them, the pore structure gradually deteriorates from III a to III C. The pore structure of this kind of reservoir is generally developed, which is a medium high porosity and medium permeability reservoir (Figure 4).

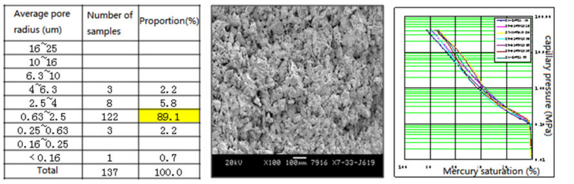


Average pore radius (um)	IIIA		IIIB		IIIC	
	Number of samples	Proportion (%)	Number of samples	Proportion (%)	Number of samples	Proportion (%)
16~25	1	1.0				
10~16	2	1.9				
6.3~10	26	25.2	2	1.3		
4~6.3	71	68.9	90	57.3	5	6.7
2.5~4	3	2.9	59	37.6	38	50.7
0.63~2.5			6	3.8	30	40.0
0.25~0.63					2	2.7
0.16~0.25						
<0.16						
Total	103	100.0	157	100.0	75	100.0

Fig. 4 Structural characteristics of type III pores

3.3.4 Microscopic characteristics of Class IV reservoirs

Type IV reservoirs are mainly silt in particle size, fine in particle size, compact in arrangement, poorly developed in pores, and poor in connectivity; the roundness is mainly sub-circular, the cementation type is mainly pore cementation, and the contact relationship is point contact; the porosity is 15 Between -30%, the average is 23.35%, the average permeability is 25.37mD, the pore throat radius is mainly distributed in the range of 0.25-6.3μm, and the pore size is mainly 0.63-2.5μm, the average displacement pressure is 0.18MPa, the maximum The average mercury saturation is 79.59%; from the characteristics of the capillary pressure curve, there is no obvious plateau in the reservoir, the distribution of pore throats in the reservoir is not concentrated, the sorting performance is poor, and the microscopic heterogeneity of the reservoir is strong. It reflects that the pore structure of this type of reservoir is poorly developed, and it is a medium-porosity and low-permeability reservoir, which is not conducive to the development of oil layers (Figure 5).

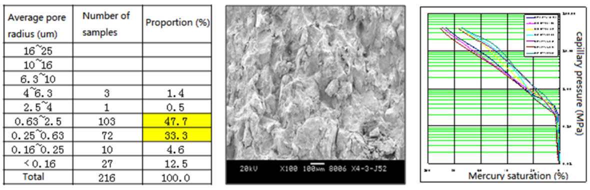


Average pore radius (um)	Number of samples	Proportion(%)
16~25		
10~16		
6.3~10		
4~6.3	3	2.2
2.5~4	8	5.8
0.63~2.5	122	89.1
0.25~0.63	3	2.2
0.16~0.25		
<0.16	1	0.7
Total	137	100.0

Fig. 5 Characteristics of class IV pore structure

3.3.5 Microscopic characteristics of V-type reservoir

Class V reservoirs are mainly silt in particle size, with fine particles and close arrangement, some of the particles are inlaid, with the worst pore development and the worst connectivity; the roundness is mainly sub-circular, and the cementation types are mainly pore cementation and film cementation. The porosity is between 7-30%, the average is 20.48%, the average permeability is 3.86mD, the pore throat radius is mainly below 6.3μm, and The pore size is mainly 0.25-2.5μm, the average displacement pressure is 0.41MPa, and the maximum mercury saturation is 78.63% on average. From the characteristics of the capillary pressure curve, the reservoir has no platform section, and the distribution of pore throats in the reservoir is not concentrated. The selectivity is the worst, and the microscopic heterogeneity of the reservoir is the strongest. It reflects that the pore structure of this type of reservoir is poorly developed, and it is a medium-porosity and ultra-low permeability reservoir, which is difficult to develop by conventional means (Figure 6).



Average pore radius (um)	Number of samples	Proportion (%)
16~25		
10~16		
6.3~10		
4~6.3	3	1.4
2.5~4	1	0.5
0.63~2.5	103	47.7
0.25~0.63	72	33.3
0.16~0.25	10	4.6
<0.16	27	12.5
Total	216	100.0

Fig. 6 Characteristics of class V pore structure

4. Optimal molecular weight of tertiary oil recovery injection polymer

The indoor research results show that when the molecular dynamic radius of polymer is 5 times less than the median pore radius R50 of oil layer, the oil layer will not be blocked. Molecular dynamics radius is an important parameter to measure whether the polymer can enter the formation. Therefore, the size of the median pore radius directly affects the level of polymer molecular weight injected into the reservoir. Based on the existing research results, the molecular dynamics radii of different polymer molecular weights are shown in the following table (Table 5).

Table 5 Molecular dynamic radius values corresponding to different polymer molecular weights

Polymer molecular weight (104)	molecular dynamics radius (μm)	Adaptive pore median R50 lower limit (μm)
650	0.148	0.74
800	0.261	1.305
1000	0.283	1.415

According to the above research results, combined with the median value of pore radius corresponding to different reservoir types, it is speculated that the molecular weight of polymer should be injected into various reservoirs in Oilfield A: class I reservoir and class II reservoir are suitable for injecting more than 10 million polymer molecular weight, class III A is suitable for injecting 10 million polymer molecular weight, class III B is suitable for injecting 8 million polymer molecular weight, class III C Class IV and class V reservoirs are suitable for injecting polymer molecular weight below 6.5 million (Table 6).

Table 6 Statistical table of molecular weight of polymers corresponding to different reservoir types

Reservoir category		Penetration (10-3μm2)	Median Pore Radius (μm)	Polymer molecular weight (104)
Class I		≥2000	14.61	>1000
Class II	A	1000-2000	9.31	>1000
	B	500-1000	6.39	>1000
Class III	A	300-500	4.38	1000
	B	100-300	1.31	800
	C	50-100	0.58	<650
Class IV		10-50	0.41	<650
Class V		< 10	0.18	<650

5. Conclusions

(1) By establishing the relationship chart between micro pore structure parameters and permeability, it is clear that there is a good correlation between permeability and each micro pore structure parameter. It is considered that the micro category of reservoir can be divided according to the size of reservoir permeability, so that the reservoir can be divided into five categories. Combined with scanning electron microscope, mineral analysis and other data, the quantitative classification and evaluation of reservoir are realized.

(2) According to the laboratory test results, combined with the microscopic characteristics of reservoirs, it is inferred that all kinds of reservoirs in Xingbei area should be injected with polymer molecular weight: Class I and Class II reservoirs are suitable for injecting more than 10 million polymer molecular weight, Class III A is suitable for injecting 10 million polymer molecular weight, Class III B is suitable for injecting 8 million polymer molecular weight, and Class III C, Class IV and Class V reservoirs are suitable for injecting less than 6.5 million polymer molecular weight.

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