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STUDY ON THE MINIMUM FLOW PORE THROAT RADIUS AND THE LOWER LIMIT OF PETROPHYSICAL PROPERTIES OF A RESERVOIR UNDER THREE SEEPAGE STATES

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Through the analysis of the reservoir seepage capacity and high-pressure mercury intrusion porosimetry, the minimum flow pore throat radius and the lower limit of petrophysical properties have been studied. The three seepage state modes include theoretical seepage, production seepage. and filling seepage. The results show that the minimum flow pore throat radius and the lower limit of petrophysical properties of theoretical seepage are the lowest in the three seepage states. The minimum flow pore throat radius and the lower limit of petrophysical properties of theoretical seepage can be used to distinguish between the reservoir and non-reservoir conditions. They can be used to distinguish between the utilized reservoir and non-utilized reservoir under production seepage and to distinguish between oil-bearing and non-oil-bearing reservoirs under filling seepage. Therefore, the reference parameters can be used for the identification of reservoirs and oil-bearing reservoirs and the study of reserves utilization degree.

Keywords: *lower limit of petrophysical properties; determination method; minimum flow pore throat radius; seepage state; reservoir.*

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1 INTRODUCTION

The minimum flow pore throat radius of the reservoir refers to the minimum throat radius of the reservoir that fluid can flow through under a certain displacement pressure. It is an important indicator to characterize the seepage capacity of the reservoir [1]. The lower limit of petrophysical properties of the reservoir refers to the minimum porosity and minimum permeability providing the storing and percolation of fluid under a certain displacement pressure. As the basis for classifying reservoir types, the parameter is usually expressed by a certain value of porosity or permeability [2]. Both the minimum flow pore throat radius of the reservoir and the lower limit of petrophysical properties are the functions of displacement pressure. When displacement pressure is constant, the seepage state of the reservoir is determined, and the minimum flow pore throat radius and the lower limit of petrophysical properties are also determined. When displacement pressure changes, the seepage state of the reservoir changes accordingly, as well as the minimum flow pore throat radius and the lower limit of petrophysical properties. Therefore, the minimum flow pore throat radius has a corresponding relationship with the lower limit of petrophysical properties of the reservoir. In the earlier studies, scholars have often used the minimum flow pore throat radius method to determine the lower limit of petrophysical properties [3-9]. According to the statistical analysis principle, this method is used to obtain correlation curves of pore throat radius and porosity and permeability, and to calibrate the corresponding lower limit of porosity and permeability according to the minimum flow pore throat radius value [10].

When the displacement pressure varies, the seepage state of the reservoir is different, and the minimum flow pore throat radius and the lower limit of petrophysical properties are also different. Therefore, evaluation of the minimum flow pore throat radius and the lower limit of petrophysical properties under a typical seepage mode state is of great importance for the analysis of reservoir seepage capacity and classification of a reservoir type. In this paper, the minimum flow pore throat radius and the lower limit of petrophysical properties have been studied by the methods of the analysis of the seepage capacity of pores at different scales in the reservoir and the high-pressure mercury intrusion porosimetry under three seepage states. The typical seepage mode states include theoretical seepage, production seepage, and filling seepage regimes.

2 SEEPAGE CAPACITY OF PORES AT DIFFERENT SCALES AND THREE SEEPAGE STATES

2.1 ANALYSIS OF SEEPAGE CAPACITY OF PORES AT DIFFERENT SCALES IN THE RESERVOIR

Reservoirs are rock formations capable of storing and infiltrating fluids. The storage space of the reservoir is composed of a network of pores of different pore throat sizes and geometric shapes. The complexity of the reservoir pore network, particularly the distribution of the pore throat size order, will inevitably and directly affect the seepage of the reservoir fluid. In the earlier studies, the scholars have divided the connected pores of the reservoir into three categories according to the pore size: super-capillary pores, capillary pores, and micro-capillary pores [11-13]. Among them, the super-capillary pore refers to a millimeter-scale pore with a pore diameter over 0.5 mm, in which the liquid can flow freely under the action of gravity. Capillary pores are micron-sized pores with a pore size ranging from 0.5 mm to 0.2 μm, in which the liquid flow is restricted by capillary forces and molecular surface tension forces on the surrounding solid interface. In the capillary pores, the liquid can only flow under the action of displacement power. Micro-capillary pores refer to nanometer-sized pores with a pore size less than 0.2 μm. In this type of pores, the intermolecular interaction forces are very high, and the liquid in the pores occurs in an adsorbed state and does not flow. Obviously, the oil-water filtration flow mainly occurs in the super-capillary and capillary pores, while the liquid in the micro-capillary pores does not demonstrate theoretical fluidity. Therefore, super-capillary and capillary pores are defined as effective pores providing for theoretical seepage, while the micro-capillary pores are considered as invalid pores [14].

Table 1

Classification basis	Connectivity	Aperture scale	Theoretical liquidity	Production fluidity	Filling liquidity
Total pore	Connected pore	Super-capillary pore	Effective pore	Flowing pore	Filling pore
		Capillary pore		Non-flowable pore	Non-fillable pore
		Micro-capillary pore	Ineffective pore	Ineffective pore	Ineffective pore
	Disconnected pore (closed pore)	Disconnected pore (closed pore)			

Table 2

Well no.	Well depth (m)	horizon	Core number	Length (cm)	Diameter (cm)	Porosity (%)	Permeability ($\times 10^{-3} \mu m^2$)
Shan 127	1951.25	Chang 6_3	1 #	6.45	2.53	12.06	0.203
Bai 221	2064.1	Chang 6_3	2 #	6.46	2.53	13.51	0.186
Bai 269	1936.27	Chang 6_3	3 #	6.1	2.53	9.21	0.123
Shan 156	2060.1	Chang 6_3	4 #	6.41	2.53	8.23	0.137
Wu 85	1991.79	Chang 6_3	5 #	6.67	2.53	6.86	0.035
Average				6.42	2.53	9.97	0.137

However, under the actual oilfield production conditions, the liquid flow in the effective pores is restricted. The flow depends mainly on the relationship between displacement pressure and seepage resistance. When the displacement pressure exceeds the seepage resistance, the liquid flows, and this fraction of effective pores is considered as the flowing pores. When the displacement power is lower than the seepage resistance, the liquid cannot flow, and this fraction of effective pores is considered as non-flowable pores. Besides, in the process of oil and gas accumulation, the effective pores are not completely filled with oil and gas, and the degree of filling depends mainly on the relationship between the filling pressure (or the reservoir-forming power) and the seepage resistance. When the filling pressure exceeds the seepage resistance, the effective pores filled with oil and gas are called the filled pores, or the pores occupied by oil and gas. When the filling pressure is lower than the seepage resistance, the effective pores that are filled with oil and gas are called unfillable pores.

In summary, under certain displacement pressures, the seepage capacity of pores at different scales in reservoirs is different. However, there are regular dependancies between the pore characteristics and the specific seepage characteristics at different scales. The relationship is summarized in Table 1. It can be seen that: 1) total pores of the reservoir > connected pores > effective pores e” flowing pores; 2) total pores in the reservoir > connected pores > effective pores e” filled pores; and 3) the relative size of the flowing pores and filled pores mainly depends on the displacement pressure and the filling pressure. When the displacement pressure exceeds the filling pressure, the flowing pores fracture is higher than the filled pores fracture. If the displacement pressure is lower than the filling pressure, the flowing pores fracture is smaller than the filled pores fracture. Among them, the effective pores correspond to the theoretical fluidity, flowing pores to production fluidity, and filled pores to the filling fluidity.

The analysis of the seepage capacity of the reservoir pores at different scales (Table 1) shows that three seepage states occur in the reservoir, that is theoretical seepage, production seepage, and filling seepage. Theoretical seepage state refers to an ideal seepage state, in which all super-capillary and capillary pores in the reservoir participate in the seepage flow. Production seepage state refers to the state in which a fraction of super-capillary and capillary pores in the reservoir participates in the seepage flow, and the degree of participation depends on the production conditions or the production pressure difference. The filling seepage state refers to the state in which the super-capillary and capillary pores in the reservoir are participating in the seepage, and the degree of participation depends on the filling pressure. For different seepage states, the minimum flow pore throat radius and the lower limit of petrophysical properties of the reservoir would also differ.

3 THE MINIMUM FLOW PORE THROAT RADIUS UNDER THREE SEEPAGE STATES AND ITS DETERMINATION METHOD

3.1. THE MINIMUM FLOW PORE THROAT RADIUS

According to the seepage state of the reservoir, the minimum flow pore throat radius can be classified by the seepage flow type, namely, the minimum flow pore throat radius of theoretical seepage, the minimum flow pore throat radius of filling seepage, and the minimum flow pore throat radius of production seepage. Among them, the minimum flow pore throat radius of the theoretical seepage corresponds to the lower limit of the capillary pore radius, and the fluid in the reservoir pore network above the lower limit demonstrates theoretical fluidity. The minimum flow pore throat radius of production seepage is the lower limit of the reservoir flowing pore radius, and the fluid in the reservoir pore throat network above the lower limit has the production fluidity. The minimum flow pore throat radius of the filling seepage corresponds to the lower limit of the reservoir filled pore radius, and the fluid in the reservoir pore network above the lower limit has a filling fluidity.

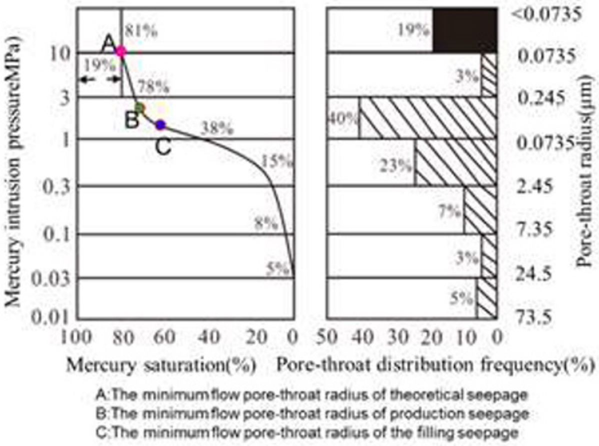

Fig. 1. **Schematic diagram of lower percolation limit.**

The minimum flow pore throat radius of theoretical seepage is the smallest among the three values, while the minimum flow pore throat radius of production seepage and the minimum flow pore throat radius of filling seepage values are relatively large. In a specific reservoir, the minimum flow pore throat radius of theoretical seepage is related to the pore structure of the reservoir. The minimum flow pore throat radius of production seepage is not only related to the pore structure of the reservoir, but also the production pressure difference. The minimum flow pore throat radius of the filling seepage is related to both the pore structure and the filling pressure.

3.2 METHOD OF DETERMINING THE MINIMUM FLOW PORE THROAT RADIUS

As can be seen from Table 1, the determination of the minimum flow pore throat radius of theoretical seepage is based on defining the boundary between capillary and micro-capillary pores. The determination of the minimum flow pore throat radius of production seepage requires is based on the boundary between the flowing and non-flowing pores. The determination of the minimum flow pore throat radius of filling seepage is based on defining the boundary between the filled pores and non-fillable pores. Therefore, the focus of determining the minimum flow pore throat radius is to clarify the reservoir pore structure and the corresponding relationship between the pore throat radius and the displacement pressure under three seepage states. At present, a number of methods are applied to study the pore structure of the reservoir. Among them, the method of high-pressure mercury intrusion porosimetry is used for the quantitative characterization of the pore structure of the reservoir and the correspondence between the pore throat radius and the displacement pressure.

When the test pressure is 100 MPa, the corresponding minimum pore radius is 7.35 nm. The working pressure of the imported mercury intrusion instrument can reach up to 400 MPa, and the minimum pore radius of 1.8 nm can be measured [15], covering the effective pore range. Therefore, the high-pressure mercury intrusion porosimetry method, production pressure difference, and oil saturation measurement method are used to determine the minimum flow pore throat radius of the reservoir. The main ideas are as follows:

1) Point A in Fig. 1 corresponds to the minimum flow pore throat radius of theoretical seepage. The minimum flow pore throat radius of theoretical seepage is the smallest, and it corresponds to the pore throat radius at the maximum mercury saturation on the mercury intrusion curve. When the intrusion pressure continues to increase, the mercury saturation remains unchanged. The initial point at which the maximum mercury saturation

remains unchanged can be regarded as the boundary point between the capillary pore fraction and the micro-capillary pore fraction, and the minimum flow pore throat radius of the theoretical seepage, as in point A.

2) Point B in Fig. 1 corresponds to the minimum flow pore throat radius of production seepage. Since the minimum flow pore throat radius of production seepage varies with the difference of the production pressure, its determination requires not only mercury intrusion data but also the production pressure difference of the oil field. The two cases are considered. First, when the pore throat radius corresponding to the production pressure difference is less than the minimum flow pore throat radius of theoretical seepage, the value is the minimum flow pore throat radius of production seepage, as shown by point B. Second, when the pore throat radius corresponding to the production pressure difference is larger than the minimum flow pore throat radius of theoretical seepage, the minimum flow pore throat radius of production seepage is equal to the minimum flow pore throat radius of theoretical seepage.

3) Point C in Fig. 1 corresponds to the minimum flow pore throat radius of filling seepage. Since the minimum flow pore throat radius of filling seepage varies with the reservoir-forming power, its determination requires not only mercury intrusion data but also the reservoir geological data. Considering the relationship between the reservoir-forming power and the original oil saturation in the reservoir, the lower limit of pore diameter of filling seepage can be comprehensively determined, as shown by point C.

4 THE LOWER LIMIT OF PETROPHYSICAL PROPERTIES OF THE RESERVOIR UNDER THREE SEEPAGE STATES AND ITS SIGNIFICANCE

Based on the minimum flow pore throat radius determination, the minimum flow pore throat radius method can be used to obtain the lower limit of petrophysical properties of the reservoir. Among them, the minimum flow pore throat radius of theoretical seepage corresponds to the lower limit of petrophysical properties

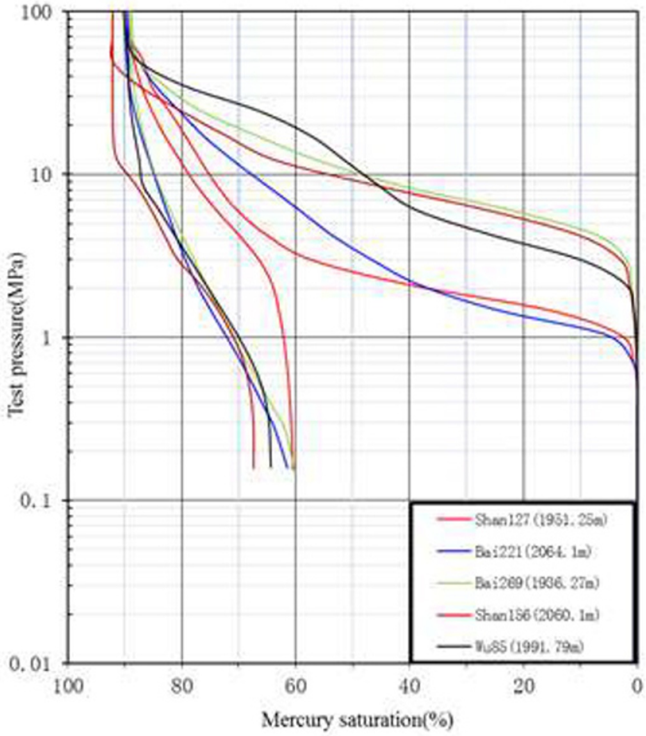

Fig. 2. **Mercury intrusion curve of the Chang 6_3 reservoir samples.**

of theoretical seepage, and that is the minimum porosity and minimum permeability of the reservoir that can store and percolate fluid in the theoretical seepage state. The minimum flow pore throat radius of production seepage corresponds to the lower limit of petrophysical properties of production seepage, that is the minimum porosity and minimum permeability of the reservoir that can store and percolate fluid in the production seepage state. The minimum flow pore throat radius of filling seepage corresponds to the lower limit of petrophysical properties of filling seepage, that is the minimum porosity and minimum permeability of the reservoir that can store and percolate fluid in the filling seepage state. The lower limit of petrophysical properties of theoretical seepage is the lowest. The lower limits of petrophysical properties of production seepage and filling seepage are relatively high and can be determined according to the relationship between displacement pressure and filling pressure. When the displacement pressure is higher than the filling pressure, the lower limit of petrophysical properties of production seepage is lower than that of the filling seepage. When the displacement pressure is lower than the filling pressure, the lower limit of petrophysical properties of production seepage is higher than that of the filling seepage.

In the actual oilfield development process, the reservoir well logging interpretation data generally include the oil layer, oil-water layer, water layer, and dry layer data. The oil and oil-water layers are generally referred to as the oil and gas storing and percolating capacity of the reservoir, or “oil-bearing reservoir”. The oil layer, oil-water layer, and water layer capable of storing and percolating fluids are collectively referred to as the “reservoir” capacity. Therefore, from the point of well logging interpretation, the lower limit of petrophysical properties of “the reservoir” differs from the lower limit of petrophysical properties of “the oil-bearing reservoir.” Since the oil-gas mixture is more likely to enter the large pore throat network with lower resistance, the lower limit of petrophysical properties of the reservoir is usually lower than the lower limit of petrophysical properties of the oil-bearing reservoir. When the minimum flow pore throat radius method is used to determine the lower limit of petrophysical properties of the reservoir, the minimum flow pore throat radius is assumed as 0.1 μm, which is equivalent to the thickness of the water film adsorbed on the surface of the clastic water-wet rock, and the oil and gas flow does not occur in the pores with a radius less than this value [3-9]. The lower limit of petrophysical properties of the reservoir here mainly refers to the oil-bearing reservoir.

The above analysis shows that the lower limit of petrophysical properties of the reservoir is the limit of porosity and permeability used to distinguish between reservoir and non-reservoir. The value is generally low and equivalent to the lower limit of petrophysical properties of theoretical seepage. The lower limit of petrophysical properties of the oil-bearing reservoir is the limit of porosity and permeability used to distinguish between oil-bearing reservoirs and non-oil-bearing reservoirs, the value is higher, and corresponds to the lower limit of petrophysical properties of filling seepage. The lower limit of petrophysical properties of production seepage depends on the production pressure and can be used as the limit of porosity and permeability distinguishing between the utilized and non-utilized reservoir. Therefore, the determination of three types of lower limits of petrophysical properties has practical significance for the identification of reservoirs and oil-bearing reservoirs, as well as for evaluating the reserves utilization degree.

5 APPLICATIONS

5.1 GEOLOGICAL OVERVIEW

The structure of the X oil field belongs to the southwest of the Yishan slope in the Ordos Basin. It is located in Huachi and Qingyang in Gansu Province, with an area of 2600 km^2. More than 300 exploration and evaluation wells have been drilled. The main production layer of the oil field is the Chang 6_3 oil group of the Upper Triassic Yanchang Formation in the Triassic system, which belongs to the gravity flow sedimentation of deep and semideep lake facies, with an average thickness of 47 m and a sand-to-land ratio of 0.52. The surface of the area belongs to the loess plateau landform, the terrain is undulating, the ground elevation is about 1150-1650 m, and the relative height difference is 500 m. The structure of the Chang 6 period is relatively simple. The overall structure is a gentle west-dipping monocline with an inclination angle of less than 1°. Analysis of core physical property data of 8288 samples from 77 cored wells shows that the porosity of the Chang 6_3 reservoir in X oilfield ranges from 4% to 15%, with an average porosity of 9.1%. The permeability is between 0.01 and 0.8 × 10^{-3} μm^2, and the average permeability is 0.152 × $10^{-3}\mu m^2$. The reservoir belongs to ultra-low porosity and ultra-low permeability reservoirs.

5.2 CHARACTERISTICS OF MERCURY-INTRUSION CURVE

Based on the rock physical properties, five samples were selected for the mercury intrusion experiment. The characteristics of the rock samples are shown in Table 2. It can be seen that the porosity of the rock samples ranges from 6.86 to 13.51%, with an average porosity of 9.97%, and the permeability is between 0.035 and 0.203 × $10^{-3}\mu m^2$, with an average of 0.137 × $10^{-3}\mu m^2$.

Figure 2 shows a mercury intrusion curve based on the mercury intrusion experimental data. The calculated parameters of the rock samples are presented in Table 3.

It can be seen that the displacement pressure of the five rock samples is between 0.78 and 2.85 MPa, with an average of 1.82 MPa. The median pressure is between 2.61 and 14.31 MPa, with an average of 8.51 MPa. The maximum pore throat radius is between 0.258 and 0.943 μm, with an average of 0.524 μm. The median throat radius is between 0.051 and 0.282 μm, with an average of 0.135 μm. The maximum mercury saturation is between 83.94 and 92.13%, with an average of 87.58%. The

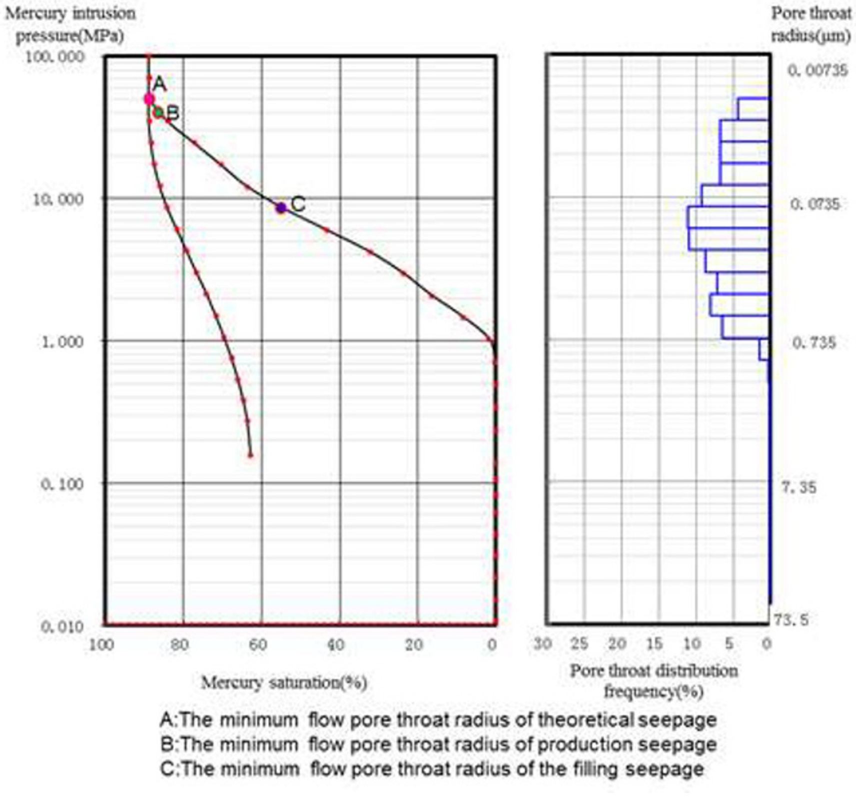

Fig. 3. The mean mercury intrusion curve and pore throat distribution of the Chang 6_3 reservoir.

mercury extraction efficiency is between 26.83 and 32.6%, with an average of 30.36%. Overall, the displacement pressure and median pressure of the Chang 6_3 reservoir are high. The median throat radius is low, with an average of 0.135 μm. The maximum mercury saturation is high, with an average of 87.58%, and the mercury extraction efficiency is low, with an average of 30.36%.

5.3 DETERMINATION OF THE MINIMUM FLOW PORE THROAT RADIUS

Based on the mercury intrusion curves of the samples in Fig. 3, the mean mercury intrusion curve of the reservoir was obtained to determine the minimum flow pore throat radius of the Chang 6_3 reservoir in X oilfield. As can be seen from Fig. 3, when the mercury intrusion pressure reaches 49.5 MPa, the maximum mercury intrusion saturation is 88.3% and remains constant with further increase in pressure. Therefore, point A is the lower limit of theoretical seepage. The calculation shows that the minimum flow pore throat radius of theoretical seepage is 0.015 *m*m. When the pore throat radius is higher than 15 *n*m, the pore network in the reservoir is theoretically permeable.

As shown by the production data statistics, the average production pressure difference of the production wells in X Oilfield is 3 MPa. Based on the field formation conditions, we assume that the oil-water interfacial tension is 25 mN/m, the wetting angle is 0°, the mercury surface tension under laboratory conditions is 480 mN/m, and the mercury wetting angle is 140° [16]. The production pressure difference is converted into the mercury intrusion pressure under laboratory conditions. The production pressure difference of 3 MPa is roughly equivalent to the experimental test pressure of 44.1 MPa. Therefore, point B in Fig. 3 is the lower limit of production seepage, and the minimum flow pore throat radius of production seepage is 0.017 *m*m. This means that the fluid in the capillary pores with a throat radius between 15 and 17 *n*m does not participate in seepage during production.

Based on the well logging interpretation results, the original oil saturation of the samples was counted. It can be seen from Table 3 that the oil saturation of the rock samples ranges between 44.3 and 74.4%, with an

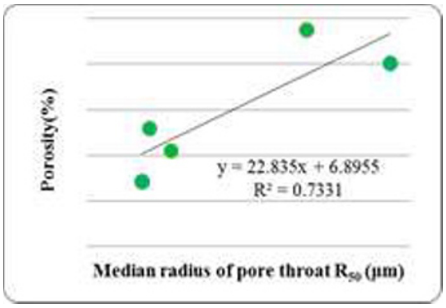

Fig. 4. Crossplot of median radius of pore throat and porosity in the Chang 6_3 reservoir.

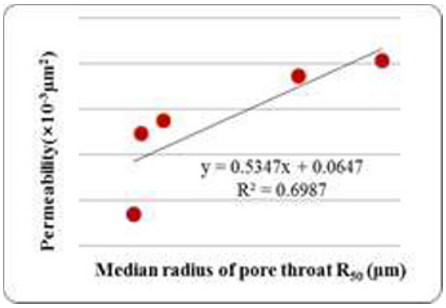

Fig. 5. Crossplot of median radius of pore throat and permeability in the Chang 6_3 reservoir

average of 56.1%. Therefore, point C in Fig. 3 is the lower limit of filling seepage, and the minimum flow pore throat radius of filling seepage is 0.085 μm. Since the minimum flow pore throat radius of production seepage is smaller than that of the filling seepage, the formation water is produced in the development process, which is consistent with the actual situation of the oilfield production.

5.4 DETERMINATION OF THE LOWER LIMIT OF PETROPHYSICAL PROPERTIES OF THE RESERVOIR

Based on the determination of the minimum flow pore throat radius in the Chang 6_3 oil layer and the statistical analysis principles, the correlation curves of pore throat radius, porosity, and permeability are established, as shown in Figs. 4 and 5. According to the minimum flow pore throat radius, the corresponding lower limits of porosity and permeability are calculated.

Figure 4 shows the intersection of the median radius and porosity of the reservoir. It can be seen that the two parameters are linearly related and the fitting relationship is as follows:

$$\mathrm{POR} = 22.8\times \mathrm{R}_{50} + 6.895 \tag{1}$$

The correlation coefficient is $R^2 = 0.733$.

Figure 5 shows the intersection of the median pore throat radius and permeability of five samples. It can be seen that the two are linearly related, and the fitting relationship is as follows:

$$\mathrm{PERM} = 0.534\times \mathrm{R}_{50} + 0.064 \tag{2}$$

The correlation coefficient is $R^2 = 0.698$.

Based on the minimum flow pore throat radius, the lower limit of petrophysical properties of the Chang 6_3 reservoir in X oilfield is calculated from Eqs. (1) and (2).

Table 3

Well no.	Core number	Displacement pressure (MPa)	Median pressure (MPa)	Maximum pore throat radius (μm)	Median radius of pore throat (μm)	Maximum mercury saturation (%)	Mercury extraction efficiency (%)	Original oil saturation (%)
Shan 127	1 #	0.98	2.61	0.750	0.282	86.67	32.60	74.4
Bai 221	2 #	0.78	3.60	0.943	0.204	87.47	31.50	66.1
Bai 269	3 #	2.85	12.63	0.258	0.058	87.67	32.19	44.3
Shan 156	4 #	2.55	9.38	0.288	0.078	92.13	26.83	49.4
Wu 85	5 #	1.93	14.31	0.381	0.051	83.94	28.66	46.2
Average		1.82	8.51	0.524	0.135	87.58	30.36	56.1

Table 4

The minimum flow pore throat radius of theoretical seepage (μm	The lower limit of petrophysical properties of theoretical seepage		The minimum flow pore throat radius of production seepage (μm	The lower limit of petrophysical properties of production seepage		The minimum flow pore throat radius of filling seepage (μm)	The lower limit of petrophysical properties of filling seepage	
	Porosity (%)	Permeability ($\times 10^{-3}\mu m^2$)		Porosity (%)	Permeability ($\times 10^{-3}\mu m^2$)		Porosity (%)	Permeability ($\times 10^{-3}\mu m^2$)
0.015	7.24	0.072	0.017	7.28	0.073	0.085	8.83	0.109

As can be seen from Table 4, the minimum flow pore throat radius of theoretical seepage is 0.015 μm, the lower limit of porosity is 7.24%, and the lower limit of permeability is 0.072 × 10^{-3} μm. The minimum flow pore throat radius of the production seepage is 0.017 μm, the lower limit of porosity of 7.28%, and the lower limit of permeability is 0.073 × 10^{-3} μm. The minimum flow pore throat radius of the filling seepage is 0.085 μm, the lower limit of porosity of 8.83%, and the lower limit of permeability is 0.109 × 10^{-3} μm.

6 DISCUSSION AND CONCLUSIONS

The minimum flow pore throat radius and the lower limit of petrophysical properties of the reservoir are not constant values. With the change in displacement pressure, the seepage state of the reservoir changes accordingly, causing the changes in the minimum flow pore throat radius and the lower limit of petrophysical properties of the reservoir. The minimum flow pore throat radius corresponding to the flow mode states in the reservoir can be summarized as the minimum flow pore throat radius of theoretical seepage, production seepage, and the filling seepage.

The minimum flow pore throat radius of theoretical seepage is related to the pore structure of the reservoir, which can be directly determined by the mercury intrusion curve. The minimum flow pore throat radius of production seepage is not only related to the pore structure of the reservoir, but is also related to the production pressure difference, so it can be determined by combining the mercury intrusion curve and the production pressure difference. The minimum flow pore throat radius of filling seepage is related to both the pore structure and the filling pressure, or the reservoir-forming power. It can be determined by combining the mercury intrusion curve and the original oil saturation data.

Based on the minimum flow pore throat radius determination, the minimum flow pore throat radius method is used to obtain the lower limit of petrophysical properties. Among them, the lower limit of petrophysical properties of theoretical seepage is the lowest, which can be used as the limit of porosity and permeability to distinguish between reservoir and non-reservoir. The lower limits of petrophysical properties of production seepage and filling seepage are relatively high. The lower limit of petrophysical properties of production seepage can be used to distinguish between the utilized and non-utilized reservoirs. The lower limit of petrophysical properties of filling seepage can be used to distinguish between oil-bearing and non-oil-bearing reservoirs. The determination of three types of lower limits of petrophysical properties has practical significance for the identification of reservoirs and oil-bearing reservoirs and the study of reserves utilization degree.

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