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Application of Conventional and Constant-Rate Mercury Injection on Microscopic Pore Structure Research

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Abstract

Microscopic pore structure features for cores in different formations are studied by conventional mercury method and constant-rate mercury method. With constant-rate mercury injection data, distribution curve feature of pore parameters are related with permeability, which including body radius, throat radius and aspect ratio distribution curve; the statistics parameters (skewness, standard deviation and kurtosis) for above three pore features are also analyzed and related to macroscopic parameters, including permeability and porosity. With conventional mercury injection data, major factors affecting reservoir producing in microscopic pore are screened with statistics methods, normalization Pc-curves are made by J function method including withdrawal curves, and compared on different permeability and formations; relationship between microscopic pore structures features and reservoir producing is analyzed, which need further research.

Key words: Conventional mercury injection; Constant-rate mercury injection; Producing state; Statistics method

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INTRODUCTION

The geometry, size, distribution and connectivity of pores and throat in cores are known as pore structure of formation. Fluid in reservoir flow through the complex pore system, passing through pores and throat alternately. Constant-rate mercury method is to injecting mercury into throat and pores in cores by quasistatic way with constant interfacial tension and contact angle, meanwhile, each pore changes encountered by mercury front will change capillary pressure in the reservoir system. Thus the size and quantity of pores and throat are measured by pressure wave, i.e. research on size and distribution of pores and throats quantitatively[1, 2].

1. APPLICATION OF CONSTANT-RATE MERCURY INJECTION DATA

Constant-rate mercury method can provide development of pore and throat, aspect ratio and its distribution. The method can provide more petrophysics parameters and more detailed information than conventional mercury method, distinguish the pore structure difference between cores, and overcome the shortcoming in conventional method that there are different pore structures with the same Pc-curve[3].

1.1 Distribution of Pore Structure Characteristic Parameters

From result of constant-rate mercury method, the distribution of throat radius, body radius and aspect ratio for cores with different permeability can be shown as Figures 1-3.

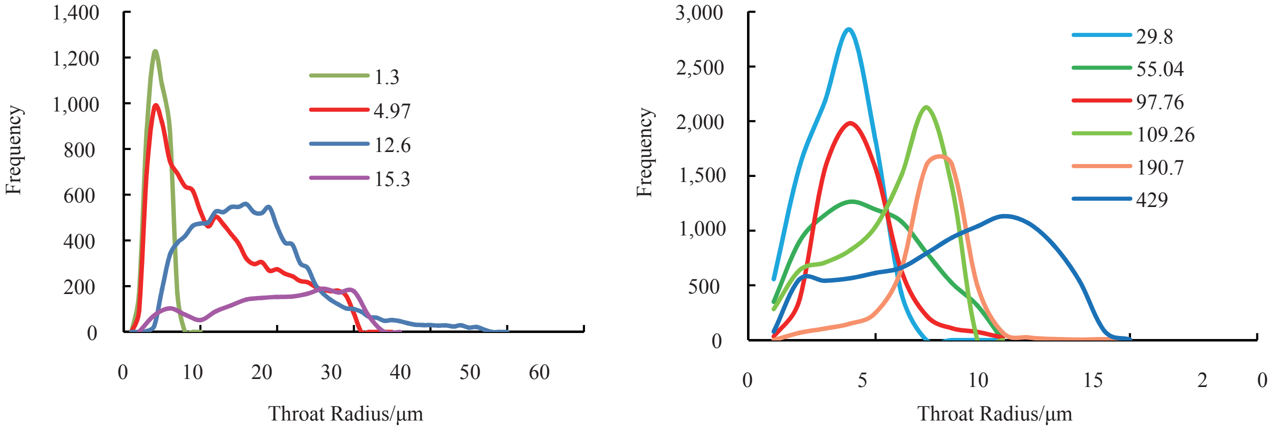


Figure 1
Throat Radius Distribution

Cores in the experiment are shown as two groups by permeability in Figure 1, where 20 mD is a limit. In both groups, higher is the permeability; lower is the frequency peak value of throat radius distribution, more dispersive is the data, and larger is the throat radius according to peak frequency.

Obviously, although there are differences between cores with lower and higher permeability, they all follow the rule that the throat radius according to peak frequency increase with the increment of permeability, that is, the sizes of most throat radiuses in formation increase with the increment of permeability. Also the peak frequency of throat radius distribution decreases as permeability decreasing.

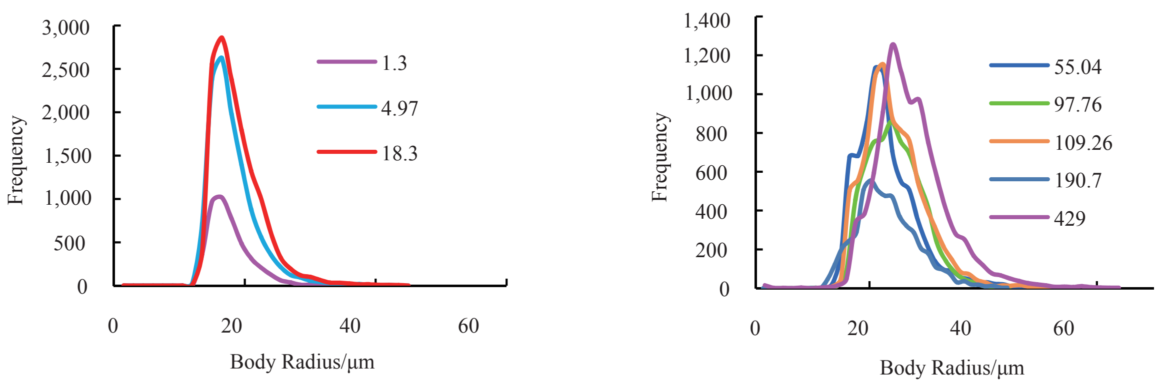


Figure 2
Body Radius Distribution

The body radius according to peak frequency in distribution in cores with lower permeability is less than 20 m, while that in core with higher permeability is larger than 20 m. The body radius distribution in group with lower permeability has single peak while that in group with higher permeability has multiple peaks.

From Figure 3 we can see that the effect of weighted mean for throat radius on permeability is more obviously than that for body radius, which means the effect of throat radius on petrophysics is much more important.

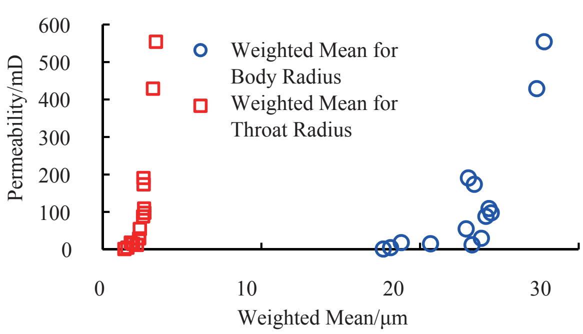
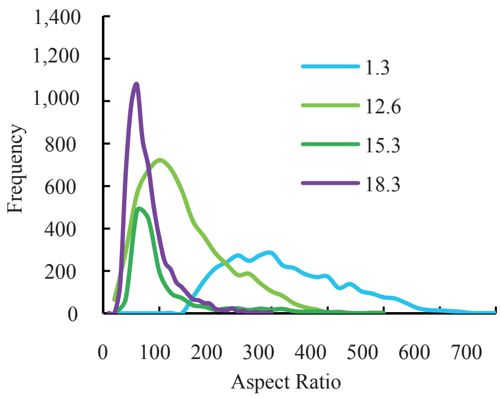


Figure 3
Influence of Weighted Mean for Body Radius and Throat Radius on Permeability



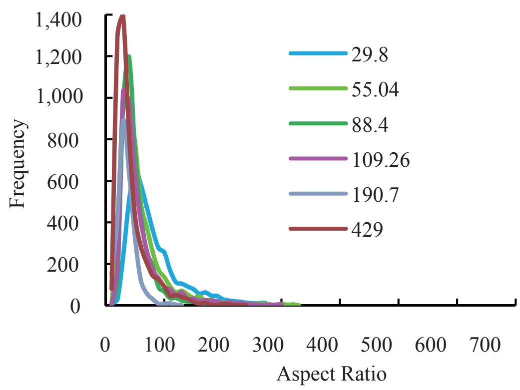


Figure 4
Aspect Ratio Distribution

From Figure 4 we can see that the aspect ratio distribution range for cores with lower permeability (20-600) is larger than that for cores with higher permeability (20-250), that is most aspect ratios in cores with higher permeability are small and their sorting is better.

Table 1
Aspect Ratio and Frequency for Peak Value in Aspect Ratio Distribution

Permeability/mD	Aspect ratio for peak frequency	Peak frequency
1.3	300	285
4.97	60	1101
12.6	100	722
15.3	60	483
18.3	60	1078
29.8	50	654
55.04	30	990
88.4	40	1196
109.26	30	1031
174	30	1049
190.7	30	889
429	30	1393
554.08	30	1209

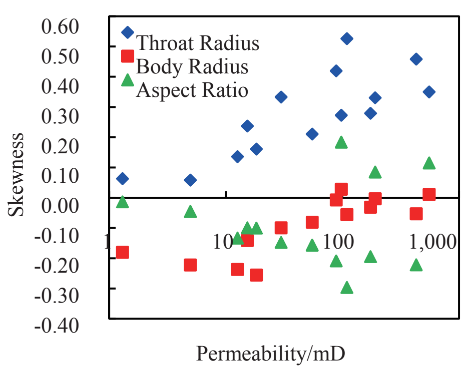
List the aspect ratio and frequency for peak value in aspect ratio distribution is shown in Table 1.

From Table 1 we can see that, when permeability is less than 100 mD, aspect ratio for peak frequency decrease with increase of permeability, while for cores with permeability larger than 100 mD, that for peak frequency keep as 30, which means for higher permeability, aspect ratio may contribute nothing to increase in permeability. In spite of this, sorting in aspect ratio may be an important factor on formation permeability.

1.2 Statistical Analysis on Characteristic Parameters Distribution

From result of constant-rate mercury injection method shows that, cores with similar weighted mean for aspect ratio or aspect ratio for peak frequency may differ greatly in permeability and porosity. Therefore, the effect of pore structure parameters distribution on permeability and porosity need further study.

Based on Folk and Wald standard, skewness, standard deviations and kurtosis are calculated with integral distribution curves, which are calculated with throat radius, body radius and aspect ratio distribution curves. The statistics analysis result is shown in Figures 5-7.



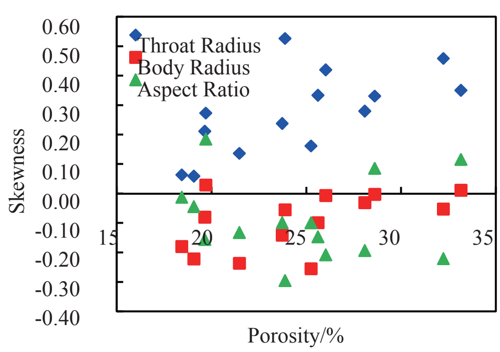


Figure 5
Relationship Between Skewness and Porosity, Permeability

From Figure 5 we can see that when the skewness of throat radius is larger, that is, the distribution tend to be coarse distribution, which means most throat radius tend to be larger, permeability and porosity get larger.

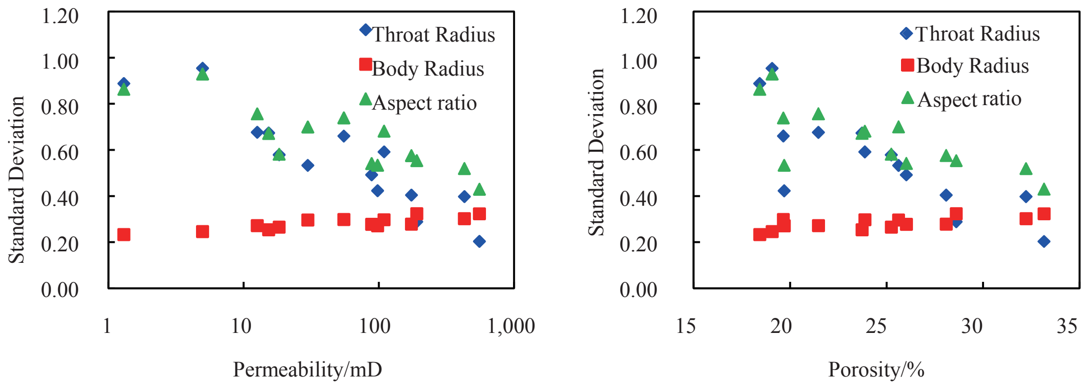


Figure 6
Relationship Between Standard Deviations and Porosity, Permeability

It can be result from Figure 6 that the standard deviations of body radius are similar for all the cores, which means sorting of their body radius are similar. While when standard deviation of aspect ratio and throat ratio get smaller, permeability get larger, it means sorting of later two has important impact on permeability of cores, and whose trends are similar, too.

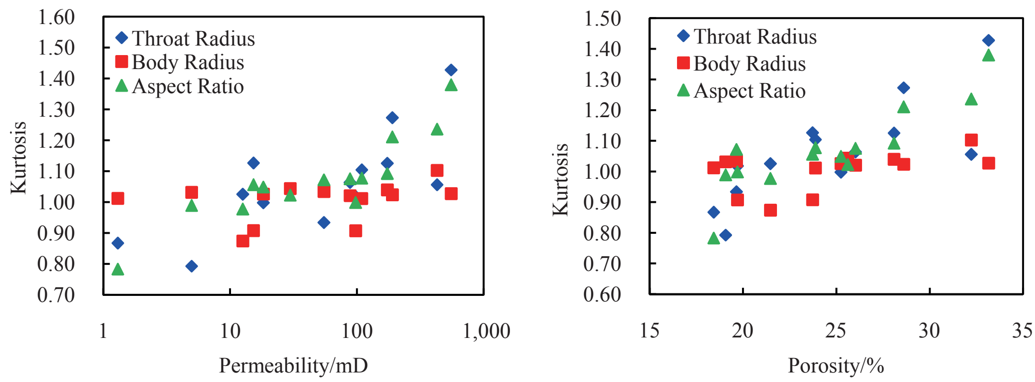


Figure 7
Relationship Between Kurtosis and Porosity, Permeability

From Figure 7 we can see kurtosis of body radius distribution are similar for most cores, which are about 1, which means they are normal distribution basically. The kurtosis of throat radius and aspect ratio increase with the increasing of permeability and porosity, in other words, thinner is their distribution peak, better is their sorting, then larger is permeability and porosity. It verifies the importance of throat feature on formation property.

2. APPLICATION OF CONVENTIONAL MERCURY INJECTION DATA

In conventional mercury injection experiment, since mercury is non-wetting phase for most cores, the capillary pressure impacting on mercury by pore structure must be overcame when injecting mercury into pore. If the injecting pressure is larger or equal to capillary pressure in pore and throat, then mercury enter the pore[1]. Based on variation in pressure and corresponding imbibitions saturation, the pore size and distribution can be measured, and the imbibitions and Drainage curve can be drawn, from which pore structure parameters can be calculated[2].

2.1 Statistics Analysis on Major factors on Pore Structures Affecting Reservoir Producing

Studies suggest that there is certain relationship between macroscopic and microscopic parameters on pore structure in formation[3]. So is the producing state in formation and microscopic pore structure features, but the relationship between them is very complex, which including macroscopic and microscopic factors. Therefore, it's very difficult to study the relationship between macroscopic producing and microscopic pore structure.

To make a trial, the conventional mercury injection data is divided into three groups by layer thickness contrasting with layer data, which are tabulated thin layer ($0 < h < 0.5$), tabulated thick layer ($h \geq 0.5$) and un-tabulated layer ($h = 0$). By the software SPSS, the relationship between producing state and mercury injection parameters is studied on the basis of displacement efficiency and the major factors affecting producing state in the parameters are screened[4].

The producing state of cores in three type formation is shown in Table 2.

Table 2
Producing State of Various Reservoirs Cores in Core Holes

	Tabulated thick layer	Tabulated thin layer	Un-tabulated layer
Producing	25	13	12
Un-producing	7	7	63
Total	32	20	75
Producing rate	78.1%	65%	16%

The producing status value is 1 for producing layers while 0 for not producing ones in analysis by SPSS. The main factors are analyzed by Logistic Regression statistical method, and "Forward: Conditional" method is chosen to screen the main factors affecting most; then Logistic Regression equation for mercury injection data is given, for example: Equation (1) for un-tabulated layer.

$$P = \frac{e^{b0+b1X1+b2X2}}{1+e^{b0+b1X1+b2X2}} = \frac{e^{4.772+0.699X1-0.111X2}}{1+e^{4.772+0.699X1-0.111X2}} \quad (1)$$

According to Equation (1), if body radius for peak frequency is $X1 = 0.025 \times 10^{-3}$ μm, and maximum mercury saturation is 87.86%, then $P \approx 0.0069$, which is near to zero and means the producing state is not producing. If body radius for peak frequency is $X1 = 6.3 \times 10^{-3}$ μm, and maximum mercury saturation is 73.06%, then $P \approx 0.7438$, which is near to 1 and means the producing state is producing. The two values are in the experiment data. The classification ability reaches 84.0%, which means the judgment of the equation is not agree with real data completely.

The parameters are screened into Logistic Regression equation are the major factors, and the software also get a coefficient B which means direct ratio ($B > 0$) or inverse ratio ($B < 0$). The result for three type layers is shown in Tables 3-4.

Table 3
Main Influence Factors for Producing State

Layer type	Tabulated thick layer	Tabulated thin layer	Un-tabulated layer
Major factors	Relative Sorting Coefficient, Median Saturation Pressure, Pore Volume, Porsosity	Relative Sorting Coefficient	Pore Distribution Peak Position, Maximum Hg Saturation
Correction Class / %	100	81	84

Table 4
Value of B for Main Influence Factors

Major factors	B	
Relative Sorting Coefficient	-258.913 (Tabulated thick layer)	-2.511 (Tabulated thin layer)
Median Saturation Pressure	-42.105 (Tabulated thick layer)	
Pore Volume	82.420 (Tabulated thick layer)	
Pore Distribution Peak Position	0.699 (Un-tabulated layer)	
Maximum Hg Saturation	0.111 (Un-tabulated layer)	

Value B is regression coefficient. For positive B, the factors are in direct ratio to producing state value P, while negative B corresponding inverse ratio. Thus, From Table 4 we can see that larger is relative sorting coefficient and median saturation pressure, more difficult to produce, while larger is pore volume, maximum Hg saturation and pore distribution peak position, easier to produce.

2.2 Normalization Pc-Curve Comparison on Different Type Formation

The Pc-curves for cores with different permeability and porosity are different. Usually, only imbibitions curve is used for reservoir evaluation with media and high permeability; while for reservoir with low and extra low permeability, imbibitions and drainage curve must be used comprehensively to describe pore, throat and their sorting more completely and objectively, and to evaluate reservoir truly[5].

Divided as above by layer thickness, Pc-curve for conventional mercury injection data is normalized with different permeability range. Normalized Pc-curves with different permeability range and layer type are contrasted to find the relationship between layer property and normalization curve shape[6, 7]. For example, in Figure 8, which is normalized Pc-curves with different permeability ranges for tabulated thick layers, it can be seen that, in tabulated thick layers, for the same Hg saturation, higher is the permeability, higher is capillary pressure, longer is the flat segment of curve, higher is the maximum Hg saturation.

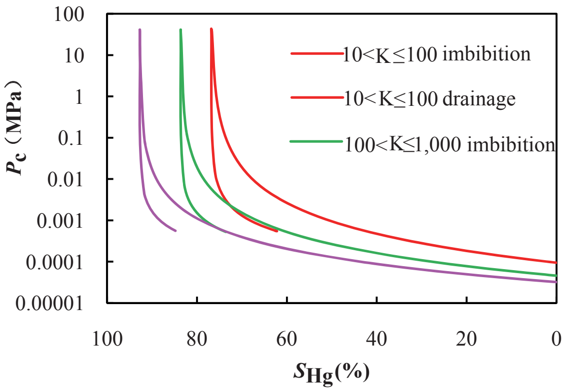


Figure 8
Normalized Pc-Curves With Different Permeability Ranges for Tabulated Thick Layers

CONCLUSION

Result of constant mercury injection experiment shows that, throat radius and body radius in tabulated thin layer and un-tabulated layer is smaller than that of tabulated thick layer, while their aspect ratio is larger; distribution range of body radius is smaller, that of aspect ratio is larger. The sorting of aspect ratio getting better may be a factor result in larger permeability.

Analyzing on the distribution of throat radius, body radius and aspect ratio by statistics we can see that, the statistics parameters of body radius distribution change little with variation of permeability and porosity, and that of throat radius and aspect ratio has important impact on core property.

Regression analysis can be used to screen major factors in microscopic pore structure affecting producing state in formation as a trial to analyze the relationship between macroscopic and microscopic parameters.

Normalization Pc-curves can make the complex Pc-curve shape easier to analyzing and contrasting.

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