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Multi-Loops of Mercury Intrusion-withdrawal Processes and the Fractal Analyses

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Abstract. Based on multi-loops of mercury intrusion-withdrawal tests, the obtained capillary pressure curves were described and the factors like the capillary hysteresis that affect the mercury withdrawal efficiency were analyzed. Then the physical implication of fractal dimensions were explained for capillary curves from different initial mercury withdrawal saturations. The results show that the multi-loops curves tested on one pore system can reflect the effects of initial fluid saturations on their withdrawal efficiencies. Along with the increase of initial mercury saturation, the recovery will increase but with less and less amount. After a threshold the recovery will nearly remain constant. The higher value of initial mercury withdrawal saturation, the more mercury that will distribute continually inside pores at the initial point. This will favor more mercury withdrawal from pores along with pressure decline. Hereinafter a smaller fractal dimension would be calculated from the withdrawal capillary pressure curves

Keywords: fractal, multi-loops, capillary pressure curves, withdrawal efficiency, fractal dimension

1. Introduction

Mercury intrusion porosimetry (MIP) is a very important tool to describe the distribution of pores & throats inside porous media [1]-[2]. In contrast with constant velocity mercury intrusion, the common mercury intrusion is easy to operate with high testing speed. All cores in different shapes can be used to get the intrusion & withdrawal capillary pressure curves and the multi-loops of mercury intrusion and withdrawal curves, so as to calculate the pore-throat parameters and to describe the inside fluid distribution [3]-[8]. Recently, fractal theory has been frequently adopted to analyze the distributing characteristics of pores & throats, but mostly on the basis of the capillary pressure curves of mercury intrusions. In reference [7], the fractal features was studies for a loop of mercury intrusion-withdrawal curve. Here a series of loops of mercury intrusion-withdrawal curves are made use of to analyze the fractal distribution of pores & throats under different initial fluid saturation points. It will reveal the correlation of fluid flowing to pores & throats distribution, then to provide reference to the construction of reservoir seepage models.

2. Measurement of Multi-loops of Mercury Intrusion-withdrawal

The mercury intrusion method takes the assumption of non-wetting mercury on most solids. The interfacial tension will be resistant to the entry of such fluid. So external pressure is required to overcome this resistance. The bigger the outside pressure, the smaller size of pores & throats to be intruded by mercury. In the mercury intrusion process, if external pressure increases gradually the mercury will fill pores & throats from outside to inside and from big pores & throats to mediate ones and then to small ones. An intrusion

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capillary pressure curves can be obtained after recording multiple pairs of external pressure & corresponding invaded mercury quantities. At the peak of mercury intrusion saturation, if the external pressure decreases gradually, the corresponding mercury withdrawal quantities can be recorded to obtain the mercury withdrawal capillary pressure curves. In the above mentioned process, a loop of capillary pressure curves will be obtained.

Then at the lowest equipment withdrawal pressure, a new re-intrusion pressure curve can be obtained if mercury is re-intruded into the same cores. As for the oil bearing rock, there is different ratio of oil and water distributing inside different parts of its pore-throat systems. To study the re-intrusion curve will help determine the oil (Non-wetting phase) recovery extent because of capillary action after pressure decline at the existence of two phases of fluids. It is far from enough to forecast the oil productivity by the information of the size of pores & throats and their distribution only, because the oil productivity is up to not only the pore structures but also the fluid saturation inside rocks. In different stages of development, the changing oil & water saturation will alter the reservoir productivity obviously.

Hence, after the withdrawal process from the first initial mercury saturation, multi-loops of capillary pressure curves could be obtained by the following re-intrusion until the last initial saturation point of mercury withdrawal, followed by the 2^{nd} withdrawal and the 2^{nd} re-intrusion and so on. Now such measurement results could be used to calculate the mercury withdrawal efficiency for each initial saturation which can forecast the recovery factor of the oil bearing formation at this existing status of oil-water distribution.

3. Characteristics of Multi-loops Curves

Fig. 1 is the capillary pressure curves with 4 loops of intrusion-withdrawal-re-intrusions which indicate:

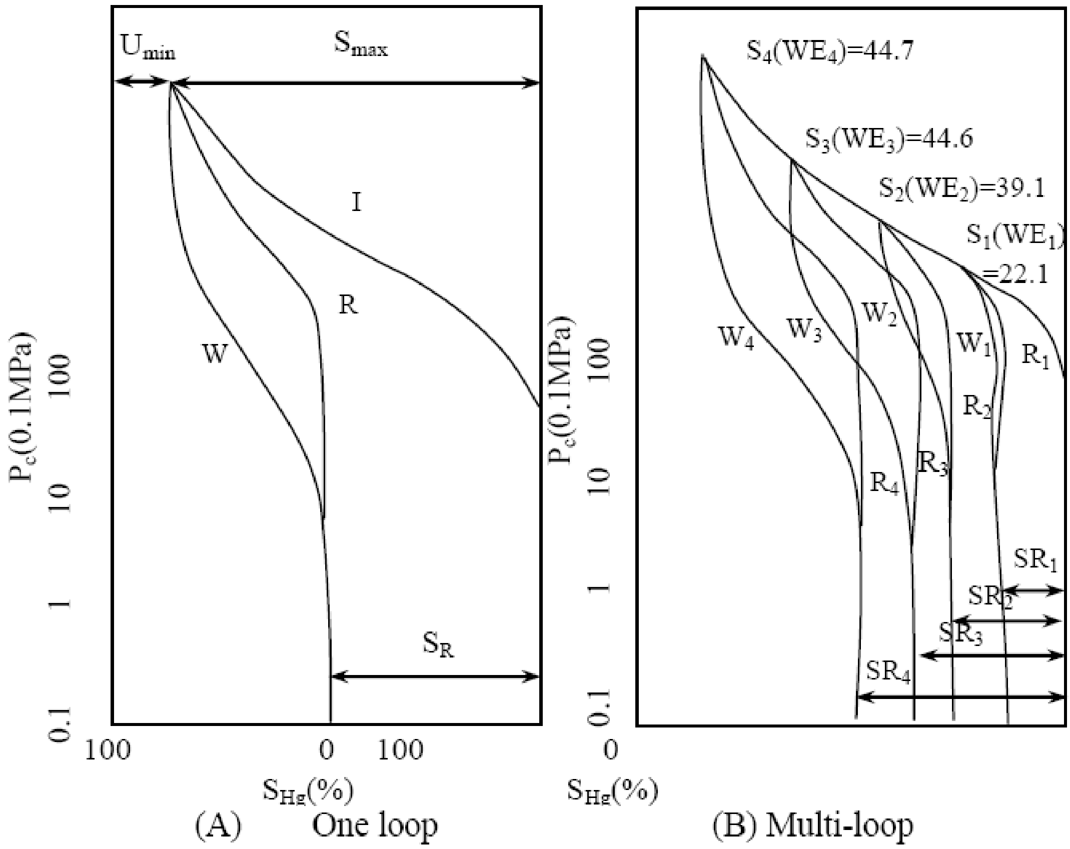

Fig. 1: Capillary pressure of a carbonate rock sample (ϕ =14.0%, K=1mD)

(1) At the minimum pressure in the withdrawal process, only a small part of mercury has flowed out of pores while the majority remained in the pores-throats system in isolated or disconnected state. This is called Trap Hysteresis which is caused primarily by pore-throat structures.

(2) In the figure, the loop that incorporates two curves of withdrawal and re-intrusion is call hysteresis loop. Its vertical distance to the saturation axis is called Blockage Hysteresis which results from fluid features as the main factors. For a given saturation, a higher pressure is required in the re-intrusion process than the withdrawal. This might be attributed to the changing contact angle or interfacial tension between the interfaces in the two processes of mercury progress and retrogress. In the progress the mercury surface enlarges while in the retrogress it contracts. At the same time, the possible pollution might also contribute to the changing contact angle or interfacial tension which would be the primary cause of Blockage Hysteresis. From the shift between work and energy, since every loop of withdrawal and re-intrusion has changed the distribution of fluids inside pores-throats, the work in the form of the loop area indicates the required energy to overcome the resistance to rebuild the new fluid distributing state.

(3) Fig. 2 is the correlation of mercury withdrawal efficiency to its corresponding initial saturation. It indicates that the mercury withdrawal efficiency will increase with the increment of the initial saturation. The extent will become less and less until the threshold value 0.6-0.7. For the oil and water system, it means the oil recovery factor will not increase in a big extent if the initial oil saturation exceeds such threshold value.

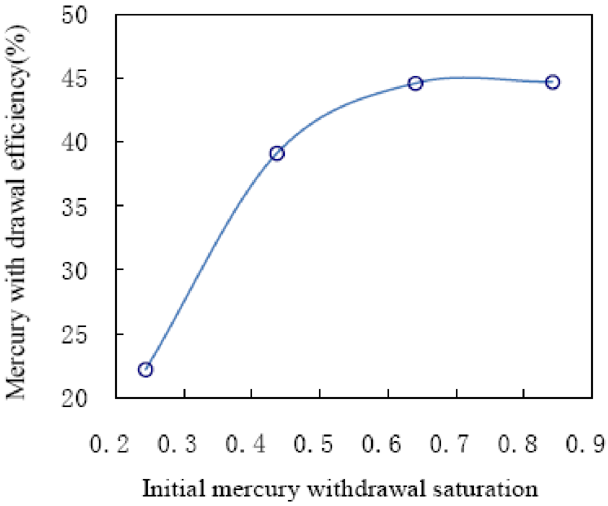

Fig. 2: Correlation of Mercury withdrawal efficiency vs. initial saturation

4. Fractal Description of Multi-loops

According to the fractal theory [3]-[4], an assumption can be made that the filling process of fractal body could be described by N(r) units with size r to completely occupy the pore space actually taken by mercury. According to the fractal model of drainage-imbibition capillary pressure curves, the log-log correlations of S_{Hg}～P_c and N(r)～r are both called Fractal Characteristic Curves.

From the references [5]-[7], the log-log correlations of both S_{Hg}～P_c and N(r)～r show good linear characteristics for withdrawal capillary pressure curves, from which a stable fractal dimension can be calculated. Fig. 3 and Fig. 4 are the fitting curves of fractal dimensions for aforesaid withdrawal capillary curves of 4 loops of curves. Fig. 5 is the correlation of withdrawal efficiencies vs. fractal dimensions of the 4 loops which show good linear feature.

Comparative analyses show the lower the initial saturation of withdrawal capillary pressure curves, the bigger fractal dimension calculated, and then the less mercury withdrawal efficiency. Because the mercury withdrawal capillary pressure curve reflects the extent of connecting flowing out of pores-throats from the initial saturation point, the calculated fractal dimension would indicate the complexity of residual mercury distributing inside pores-throats. The lower initial point of mercury withdrawal saturation, the more complexity of the residual mercury in pores-throats, the easier isolation & disconnection of mercury and then the less oil recovery factor from such cores. On the contrary, the higher initial point of withdrawal saturation, the more mercury will distribute connectedly inside pores-throats at the beginning. It will help orderly withdrawal of mercury under the decrease of pressure.

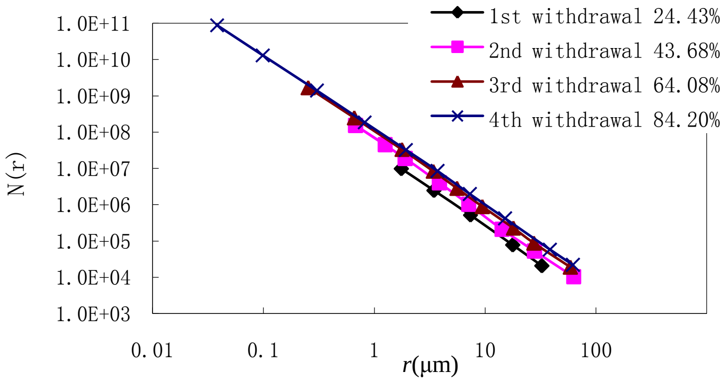

Fig. 3: Log-log curve of N(r) vs. r for the carbonate rock sample

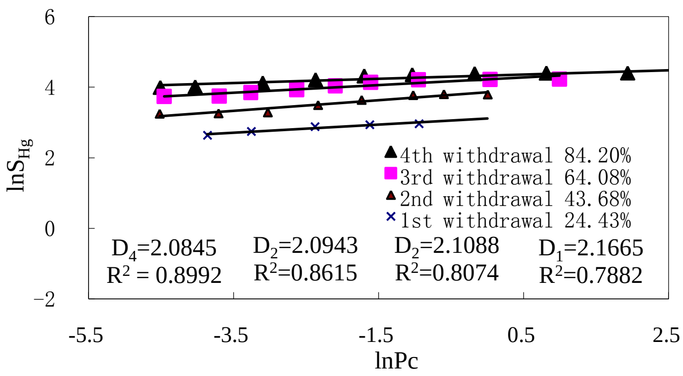

Fig. 4: Log-log curve of SHg vs. Pc for the carbonate rock sample

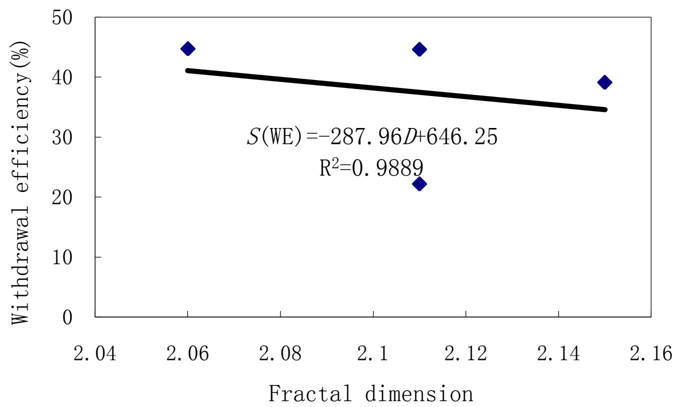

Fig. 5: Correlation of mercury withdrawal efficiency vs. fractal dimension for the carbonate rock sample

5. Conclusions

The multi-loops of intrusion-withdrawal capillary pressure curves obtained by MIP are used to analyze the capillary hysteresis that affects withdrawal efficiency and the physical significance of fractal dimensions calculated from curves at different initial point of mercury saturations. It concludes as follows:

(1) The multi-loops of mercury intrusion-withdrawal curves can reflect the correlation of fluid flow features at different initial point of mercury saturations inside the same pore-throat system. The two primary factors that affect the mercury withdrawal efficiency should be the trap hysteresis and blockage hysteresis.

(2) The mercury withdrawal efficiency will increase due to the increment of the initial saturation. The extent will become less and less until the threshold value 0.6-0.7. For the oil and water system, it means the oil recovery factor will not increase in a big extent if the initial oil saturation exceeds such threshold value.

(3) The lower the initial point of mercury withdrawal saturation, the more complexity of the residual mercury in pores-throats, the easier the isolation & disconnection of mercury and then the less oil recovery

factor from such cores. On the contrary, the higher initial withdrawal saturation, the more mercury will distribute connectedly inside pores-throats at the beginning. It will help orderly withdrawal of mercury under the decrease of pressure.

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