An Experimental Study on Starting Pressure of Low Mobility Oil Reservoir

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Abstract — The low mobility oil reservoir refers to the reservoir whose mobility is less than $30 \times 10^{-3} \mu m^2/mPa\cdot s$. The experimental research shows that a low mobility reservoir has starting pressure gradient whose magnitude is related to the permeability of reservoir rocks and the viscosity of fluid. In general, when the fluid's viscosity is constant, with the increase of reservoir permeability, the starting pressure gradient is smaller. And starting pressure gradient and permeability meet a change of power exponent. Considering the relationship among starting pressure gradient and permeability of reservoir rocks, the viscosity of fluid, namely starting pressure gradient and mobility also have a change of power exponent with positive correlation. With the increase of mobility, starting pressure gradient has an obvious decreased tendency.

Keywords — low mobility, reservoir, starting pressure gradient, permeability, well spacing

I. INTRODUCTION

Mobility expresses the difficulty of the fluid flow in the reservoir\cite{1}. It is the ratio of the air permeability of reservoir rocks and underground crude oil viscosity ($\lambda = K/\mu$). Reservoirs that mobility is less than $30 \times 10^{-3} \mu m^2/mPa\cdot s$ are low mobility reservoirs.

Generally, the low-permeability sandstone reservoirs possess some characteristics, such as low permeability, porosity based with low and middle porosity, cements (clay mineral, etc,) content higher and so on\cite{2,3}. This makes the specific surface of reservoir pore spaces large, and the contact area between fluid and solid large too. So the percolation resistance is much higher than the high and middle permeability reservoirs'. Thus, in the development process, the low permeability reservoirs often cause the phenomenon of the injection wells not water injection and the oil wells not production \cite{4,5}, because it’s difficult to form effective displacement pressure between the injection-production wells\cite{6,7}.

After the indoor experiment methods of research, many scholars think that low permeability reservoirs exist starting pressure or starting pressure gradient \cite{8-10}, that is to say fluid need achieve certain starting pressure, when it flows in low permeability reservoirs. This view is widely accepted, but there are also some scholars questioned this view on starting pressure. They hold that not starting pressure has been measured in this experiment \cite{11}, while starting pressure just is the illusion because pressure speeds slowly in the low permeability reservoir \cite{12-14}. These two views has been controversial \cite{15,16}.

In fact, the so-called starting pressure should be the biggest percolation resistance that fluid need overcome when fluid occur movement in low permeability reservoirs. The biggest percolation resistance is produced by the interaction between solid and fluid. It both is associated with the physical properties of reservoirs, also is related to the nature of the fluid. For example, gas or light oil can move in low permeability reservoirs without large displacement differential pressure, while even in high permeability reservoirs heavy oil with high viscosity still need large displacement differential pressure to move \cite{17}.

In order to verify the magnitude of percolation resistance in the low permeability sandstone reservoir and its influencing factors, this article researches the relationships among the percolation resistance and the core length, the core permeability, the fluid viscosity and the mobility through the indoor experiment.

II. TYPE OF LOW MOBILITY RESERVOIRS

According to the definition of mobility and the low mobility reservoirs, low mobility reservoirs is not only low permeability reservoirs, it should include a part of heavy oil reservoirs with high permeability but high underground crude oil viscosity, routine reservoirs with low permeability but high underground crude oil viscosity, and low
permeability reservoirs with low permeability. The relationships among the classification of low mobility reservoirs and heavy reservoirs, low permeability reservoirs can be described through Figure 1.

From the chart, low mobility reservoirs can be divided into three types, one is the conventional low mobility reservoirs, the other two are low mobility reservoirs of heavy oil and low mobility reservoirs of low permeability. The classification standards of these three types’ low mobility reservoirs and low permeability and heavy reservoirs are shown in Table 1.

![Figure 1. The relationship between the various reservoir types](image)

<table>
<thead>
<tr>
<th>Reservoir types</th>
<th>Mobility ($10^{-3}$μm²/mPa·s)</th>
<th>Permeability ($10^{-3}$μm²)</th>
<th>Oil’s subterranean viscosity (mPa·s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heavy reservoirs</td>
<td>General ≥30</td>
<td>—</td>
<td>≥50</td>
</tr>
<tr>
<td></td>
<td>Low mobility &lt;30</td>
<td>—</td>
<td>≥50</td>
</tr>
<tr>
<td>Low permeability reservoirs</td>
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<td>&lt;50</td>
<td>—</td>
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<tr>
<td></td>
<td>General ≥30</td>
<td>&lt;50</td>
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The low mobility reservoirs that the mobility is less than $30 \times 10^{-3}$μm²/mPa·s, according to its productive characteristics and actual requirement, can be further divided into the following three types by reference to the classification methods of low permeability reservoirs.

Generally, the first one is the low mobility reservoir. The average mobility for the reservoir is $30 \times 10^{-3}$μm²/mPa·s~$10.1 \times 10^{-3}$μm²/mPa·s. This kind of reservoir is close to the normal reservoirs. Oil wells can achieve to the standard of industrial oil flow, but the production is too low. Low permeability reservoirs need improve the production capacity by using fracturing methods. By this they can acquire better development effect and economic benefit. Heavy oil reservoirs need to be taken steam huff and puff, in situ combustion, technical of chemical viscosity reduction, emerging heavy oil cold producing techniques and other special technological measures and methods to effectively exploitation.

The second one is the extra-low reservoir. The average mobility for the reservoir is $10.0 \times 10^{-3}$μm²/mPa·s~$1.1 \times 10^{-3}$μm²/mPa·s. This kind of reservoir is different from the normal reservoir obviously. It belongs to the low mobility reservoir. Generally, the irreducible water saturation of the extra-low reservoir that low permeability causes increases, the logging resistivity reduces and the normal test cannot be up to the standard of industrial oil flow. So large fracturing treatment and other corresponding measures must be taken, they can be in industrial
development, such as Changqing Ansai Oilfield (in Yan'an City, Shanxi Province, China), Daqing Yushulin Oilfield (in Zhaodong City, Heilongjiang Province, China), and Jilin Xinmin Oilfield (in Songyuan City, Jilin Province, China) and so on. While only taking some unconventional technics of oil production, the extra-low reservoir that the high viscosity of crude causes can be developed effectively.

The third one is the ultra-low reservoir. The average mobility for the reservoir is less than $1.0 \times 10^{-3} \mu m^2$/mPa·s. The oil layer of this kind of reservoir is very compact or the viscosity of crude is extreme high, the irreducible water saturation is high, and there is not natural productivity basically. Ordinarily, this kind of reservoir has no the value of industrial development. But if there are other favorable conditions, such as the oil layer is thicker, it buries shallowly and so on, it can also be for industrial development and require some economic benefit by taken some effective measures that can increase the oil production and can reduce the investment and cost, such as the Chuankou Oilfield of Yanchang, and a part of heavy reservoirs of Dagang also belongs to ultra-low reservoirs.

III. THE EXPERIMENT OF THE STARTING PRESSURE

A. The Experimental Samples

The all samples used in this experiment were taken from different blocks of southern development areas of Dagang Oilfield, in the Member 2 of Kongdian Formation. The total is 70 samples. The porosity ranges from 6.42% to 22.89%, and the air permeability's range is $0.183 \sim 752.66 \times 10^{-3} \mu m^2$. These samples were measured air permeability after washing oil and drying and were divided into four grades ($0.1 \sim 1, 1 \sim 10, 10 \sim 50$ and $>50 \times 10^{-3} \mu m^2$).

B. The Experimental Conditions

The experimental fluid is kerosene and simulated oil. The viscosity of kerosene is 2.38mPa·s and the density is 0.8075g/cm$^3$. The simulated oil is made from transformer oil and kerosene, one’s viscosity is 7.36mPa·s, the density is 0.8109g/cm$^3$, and the other’s viscosity is 14.5mPa·s, the density is 0.8234g/cm$^3$. The experimental temperature is 70℃. (Because the viscosity of crude is too high, it need very high temperature to achieve the above three grades, while the too high temperature will influence the measure of the starting pressure. So we adopted the viscosity that diluted kerosene achieve the above three grades in the conditions of 70℃).

C. The Experimental Theory

This test method of the starting pressure is bubbling test. The theory is that when the core is full of fluid, the pressure need conquer the biggest throat resistance in the core and the interfacial tension between fluids, etc, in the process of displacement pressure from low to high pressure. At the moment, the displacement fluid is about to start getting into the hole and occupying the hole volume. Owing to the transfer of pressure, the fluid starts flowing, so the tube of the core outlet starts producing bubbles, the core inserts in water. We consider this pressure the starting pressure. The test method is called bubbling test.

D. Steps of the Starting Pressure Experiment

First of all, the core will be saturated 100% curd oil. In the condition of the experimental temperature that is designed, keep the test system homothermic.

Then in the conditions of designed experiment, displace with oil from low pressure to high pressure, until the starting pressure is determined.

IV. THE CHARACTERS OF THE STARTING PRESSURE GRADIENT

A. The Relationship of the Starting Pressure Gradient and Permeability

In the experiment, we select three experimental fluid and different permeability’s cores to make the tests of initial percolation resistance gradient respectively. One fluid is kerosene, its viscosity is 2.38mPa·s and density is 0.8075 g/cm$^3$. The number of test cores is 24, the permeability ranges $0.183 \sim 360.34 \times 10^{-3} \mu m^2$. Another is simulated oil (it’s compounded by transformer oil and kerosene). The viscosity is 7.36mPa·s and the density is 0.8109 g/cm$^3$. The number of test cores is 23, the range of permeability is $0.267 \sim 311.27 \times 10^{-3} \mu m^2$. The third fluid is that
compounded by transformer oil and kerosene. Its viscosity is 14.5mPa·s and density is 0.8234g/cm³. The number of test cores is 23, the range of permeability is 0.184×752.66×10⁻³ μm², the average of experimental temperature is 70℃. The experimental result is shown in Figure 2 to Figure 4.

For three different fluids, the smaller the core permeability is, the greater the value of corresponding to the starting pressure gradient is. When the air permeability is less than 10×10⁻³ μm², the starting pressure gradient variation is the largest. After the regression analysis of the values of starting pressure gradient and the corresponding experimental dates of air permeability, we get the relation curves (Figure 2 to Figure 4) and the regression equation between the starting pressure gradient and the air permeability.

\[
\lambda = 0.9471K^{-0.5989} \mu = 2.38mPa.s \quad R^2 = 0.9921 \tag{1}
\]

\[
\lambda = 1.4735K^{-0.5384} \mu = 7.36mPa.s \quad R^2 = 0.9969 \tag{2}
\]

\[
\lambda = 1.8542K^{-0.5355} \mu = 14.5mPa.s \quad R^2 = 0.9997 \tag{3}
\]

In the equation:

- λ—starting pressure gradient, MPa/cm;
- K—permeability of the core samples, ×10⁻³ μm²;
- μ—the viscosity of fluid, mPa.s.

From above equations, we can know that the rocks’ air permeability and the starting pressure gradient exists relationship as follows:

\[
\lambda = aK^{-n} \tag{4}
\]

In the equation (4), a and n are constants related to lithology and fluid properties. From this, rocks’ air permeability has the exponential relationship with the starting pressure gradient.

From figure 2 to figure 4, with the core permeability increasing to some value, the larger the rocks’ air permeability is, the smaller the starting pressure gradient is.
and the change is steady. When the core permeability reduces to some value, with rocks’ air permeability reducing, starting pressure gradient rises rapidly. It shows that average stratum permeability is significant influence on the value of starting pressure gradient for low permeability fields.

B. The Relationship of Starting Pressure Gradient and Mobility

From the experimental results in the figure 2 to the figure 4, when the rocks’ air permeability is constant, with the increase of fluid viscosity, the rocks’ starting pressure gradient increases. In other words, when fluid flows in rocks, the larger the fluid viscosity is, the greater the rocks’ resistance flowed fluid is. The great resistance means that the stronger the interaction between fluid and solid is, the larger the starting pressure gradient to make the high viscosity’s fluid flow.

The change relationship between starting pressure gradient measured with the same kind of fluid viscosity and mobility should be consistent with that between it and permeability. It only changes the K to $\frac{K}{\mu}$ in equation (1) to equation (4), and the coefficient “a” also changes, other parameters are totally consistent. We conduct the percolation experiment respectively with three kinds of viscosity’s fluid and different permeability’s cores in the experiment. Allowing for the impacts of mobility on starting pressure gradient, we make the double logarithmic relation curve between all samples starting pressure gradient and mobility, just as figure. 6. From figure 6 the relationship of starting pressure gradient and mobility is as follows:

$$\lambda = 0.491 \cdot \left(\frac{K}{\mu}\right)^{0.5423}$$  \hspace{1cm} (5)

$$\lambda = a \cdot \left(\frac{K}{\mu}\right)^{b}$$  \hspace{1cm} (6)

Equation (6) is the relation equation of starting pressure gradient and mobility from the experiment. If permeability of reservoir rocks and viscosity of crude are known, we should get the starting pressure gradient of reservoir rocks with that equation.

Figure 5. The relationship graph of starting pressure gradient and permeability for all samples

Figure 6. The relationship curve of starting pressure gradient and mobility for all samples

V. CONCLUSIONS AND SUGGESTIONS

The low mobility reservoir has starting pressure gradient. And the values of starting pressure gradient are relation with the permeability of reservoir rocks and the viscosity of fluid. Generally speaking, with increase of reservoir permeability, in the condition of certain fluid viscosity, starting pressure gradient is smaller. And it meets the change relation of power exponent between starting pressure gradient and permeability.

Synthesizing the relation among starting pressure gradient, reservoir rock permeability and fluid viscosity, we can get that it have the change relation of power exponent
with very good correlation between starting pressure gradient and mobility. And with the increase of mobility, starting pressure gradient has obvious decrease tendency.

REFERENCE


