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# Investigation on Actuating Pressure Gradient of Low Permeability Reservoir

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## Abstract

Due to the presence of actuating pressure of low permeability reservoir, researching on actuating pressure gradient of low permeability reservoir is necessary. While actuating pressure gradient is relevant to permeability and porosity, it can be obtained through laboratory experiments, well testing interpretation method and theory derivation combined with practical application method. The results of a large number of laboratory experiments show that actuating pressure is related to permeability. The greater the permeability is, the smaller the actuating pressure is. They both present the similar hyperbolic relationship; the greater the viscosity of the oil is, the greater the actuating pressure is. Here, we get the actuating pressure gradient formula through the method of theory derivation combined with practical application, meanwhile we put forward the relationship between actuating pressure gradient and permeability, porosity and viscosity.

**Key words:** Low permeability reservoir; Actuating pressure gradient; Porosity; Fluid viscosity

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## INTRODUCTION

The study shows that the actuating pressure gradient is influenced by the porosity, permeability and fluid limiting shear stress; in addition, the study also shows that the greater the viscosity of crude oil is, the greater the thickness of the boundary layer of oil is[1]. In other words, oil viscosity is proportional to the thickness of the boundary layer of crude oil, so it can be inferred, the viscosity increases, the limiting shear stress increase , that is to say that the viscosity is proportional to the limiting shear stress. Therefore, assume that actuating pressure gradient is proportional to the viscosity. With the usage of this formula and field data, we can get actuating pressure gradient regression formula in different regions[2].

## 1. THE ACTUATING PRESSURE DERIVATION

Newtonian fluid flows in the capillary flow of linear follow Darcy's law, while crude oil belongs to plastic fluid, namely, non-Newtonian fluids. According to rheology, when plastic fluid flows in the capillary, the relationship between shear stress and limiting shear stress, plastic viscosity and velocity gradient can be shown with Bingham formula[3]:

$$\tau = \tau_0 + \mu \frac{\mathrm{d}V}{\mathrm{d}r} . \tag{1}$$

In order to facilitate the study, we can simplify the natural core as the idealized model that is made of several capillary tubes. Meanwhile, the relationship between the porosity of the rock, permeability and capillary radius is:

$$r = \sqrt{\frac{8K}{\phi}} . \tag{2}$$

 

The average velocity of the plastic fluid in the capillary can be presented with capillary length, driving pressure and other parameters:

$$\bar{v} = \frac{r^2}{8\mu l}\left(\Delta p - \frac{8l}{3r}\tau_0\right). \quad (3)$$

Namely, $\bar{v} = \frac{r\Delta p}{2l} \times \frac{r}{4\mu} - \frac{r}{3\mu}\tau_0$. (4)

To the capillary whose radius is $r$, the shear stress at the wall is:

$$\tau = \frac{r}{2l}\Delta p. \quad (5)$$

The state of laminar flow of the plastic fluid is similar to Newtonian fluid's, so:

$$\tau = \frac{r\Delta p}{2l} = \mu\frac{\mathrm{d}v}{\mathrm{d}r}. \quad (6)$$

Combine Equation 6 with Equation 4:

$$\mu\frac{\mathrm{d}v}{\mathrm{d}r} = \frac{4\mu\left(\bar{v} + \frac{r}{3\mu}\tau_0\right)}{r}, \quad (7)$$

$$\frac{r\Delta p}{2l} = \frac{4\mu\left(\bar{v} + \frac{r}{3\mu}\tau_0\right)}{r} + \tau_0. \quad (8)$$

For the core, its seepage velocity can be expressed by yield ($q$) and core cross-sectional area ($F$):

$$\bar{v} = \frac{q}{\phi F}. \quad (9)$$

Through the arrangement of the equations above:

$$q = \frac{KF}{\mu}\left(\frac{\Delta p}{l} - \frac{7}{3}\tau_0\sqrt{\frac{\phi}{2K}}\right), \quad (10)$$

$$\bar{v} = \frac{K}{\phi\mu}\left(\frac{\Delta p}{l} - \frac{7}{3}\tau_0\sqrt{\frac{\phi}{2K}}\right). \quad (11)$$

Equations 10 & 11 are the seepage law of single-phase flow in the low permeability reservoirs. From Equations 10 & 11 can be seen, once $\frac{\Delta p}{l} > \frac{7}{3}\tau_0\sqrt{\frac{\phi}{2K}}$, the fluid flow occurs. So the actuating pressure is:

$$\frac{\Delta p}{l} = \frac{7}{3}\tau_0\sqrt{\frac{\phi}{2K}}. \quad (12)$$

Annotation: $\phi$- Porosity;
$K$ - Permeability,$10^{-3}$ $\mu m^2$ ;
$\tau$- Limiting shear stress, $g/cm^2$;
$\Delta p/l$ - Actuating pressure gradient, *MPa/m*.

## 2. THE DETERMINATION OF ACTUATING PRESSURE GRADIENT

As can be seen from the formula, actuating pressure gradient is influenced by reservoir porosity、permeability and limiting shear stress. According to the definition and study of $J$ functions ( $J = \frac{p_c}{\delta}\sqrt{\frac{\phi}{K}}$ ), $\sqrt{\frac{\phi}{K}}$ depends on the size of the pore structure of the rock. If $\sqrt{\frac{\phi}{K}}$ is the same, the capillary pressure curve is basically the same. Different types of rocks form different J functions. Therefore, for the same type of rock, actuating pressure gradient with $\sqrt{\frac{\phi}{K}}$ becomes direct ratio. In addition, studies show that the bigger oil viscosity is, the greater the thickness of the boundary layer of crude oil is[4]. Namely, the viscosity of crude oil is proportional to the thickness of the boundary layer of crude oil. So it can be inferred, when the viscosity increases, the limiting shear stress increases. The viscosity is proportional to the limiting shear stress. Therefore, we can assume that the most essential impact on actuating pressure gradient is fluid viscosity, namely, the actuating pressure is directly proportional to the viscosity.

Therefore, from a practical point of view, for the same type of rock, actuating pressure gradient Equation (12) can be rewritten as:

$$\lambda = m\mu\sqrt{\frac{\phi}{K}}. \quad (13)$$

Annotation: $m$ - undetermined coefficient.

According to the actuating pressure gradient and the formation parameter that is shown in the Table (refer with Table 1), $X = \mu\sqrt{\frac{\phi}{K}}$ is used as abscissa, and $Y = \lambda$ is used as ordinate. We can get the relation curve (Figure 1). In order to unify equation (Equation 13), the intercept of the regression line is set equal to 0, the regression result can be expressed:

$$\lambda = 0.0069\mu\sqrt{\frac{\phi}{K}}. \quad (14)$$

**Table 1**
**Test Data Table of Actuating Pressure Gradient of Daqing Changyuan Sheet Reservoir**

| Porosity (%) | Permeability ($10^{-3}$ μm$^2$) | Viscosity (mPa·s) | Actuating pressure gradient (MPa/m) |
|---|---|---|---|
| 17.2 | 19.2 | 6.8 | 0.016 |
| 17.3 | 20.3 | 8.2 | 0.018 |
| 17.1 | 18.2 | 8.5 | 0.017 |
| 16.25 | 18.6 | 7.6 | 0.019 |
| 16.35 | 7.9 | 11.6 | 0.035 |
| 16.2 | 5.6 | 13.4 | 0.046 |
| 17.2 | 7.0 | 9.6 | 0.033 |
| 17.3 | 7.8 | 7.9 | 0.028 |
| 17.1 | 6.4 | 8.2 | 0.031 |

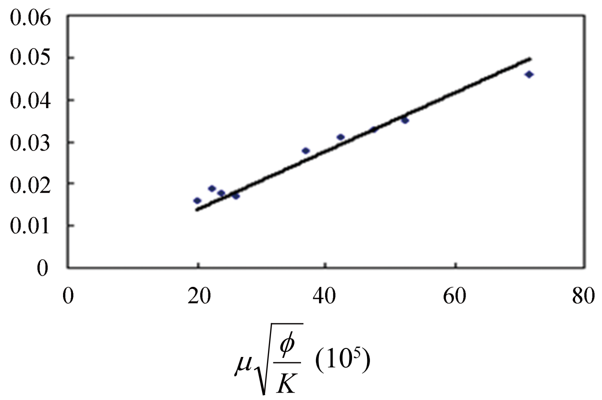


**Figure 1**
**The Relationship Between Actuating Pressure Gradient and Permeability, Porosity and Viscosity**

As can be seen from Figure 1, staring pressure gradient is not only related to permeability, but also can be influenced by the porosity and the viscosity. Actuating pressure gradient becomes bigger with rock porosity and the fluid viscosity increasing, meanwhile it decreases with increasing permeability[5].

## CONCLUSION

Through research and analysis, we get the following conclusions:

(a) This paper gets the start-up pressure gradient formula by mainly using the method of theory combining with experiment, and puts forward the relationship between the start-up pressure gradient and permeability, porosity and viscosity.

(b) Study shows that the limiting shear stress increases with the viscosity increasing, the viscosity is proportional to limiting shear stress. Therefore, assuming that the fluid properties have influences on the start-up pressure gradient and viscosity, that is, the start-up pressure is proportional to the viscosity of the fluid.

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