Numerical Simulation of Two - Phase Percolation under External Electric Field

Lianwei Zhang, Jianjun Xu *, Lin Huang, Aihua Xu, Fan Yang, Fanxu Meng, Yanjun Zhang

Department of Electrical Information Engineering, Northeast Petroleum University, Daqing, 163318, China

Corresponding Author: Xu Jianjun, 123939274@qq.com

Abstract

This paper set up the model with the action of external electric field of the permeation and streaming law of two phase in different structures based on electron-osmosis theory. And then obtain exact solution of the problem by using analytic method of COMSOL Multi-physics. Analyzed the consistency of the water saturation and the water phase relative permeability on the relative permeability curve in theory, it is also discussed that the water saturation is lower when the applied electric field exists, than that in the absence of the electric field, finally validation the correctness of the two phase flow mathematical model in gap medium under applied electric field. Finally, It is determined that 160V is the optimum electric potential of the applied electric field.

Keywords

Crevice Medium, Recovery Ratio, Water Saturation.

1. Introduction

In order to investigate the effect of the external electric field on the two-phase seepage in different fracture width models, then completing the numerical calculation and the result analysis of the two-phase seepage in different fracture opening models under the electric field.

Description of the relevant parameters of the fracture media model:

(1) The size of model is $L \times W \times H = 60 \times 30 \times 30$ cm^3, the direction of the infiltration is along the length direction, $W \times H$ represents the two-dimensional plan of seepage.

(2) The fracture structure can be defined as: The vertical gap parallel to the width direction is the vertical vertical gap; the horizontal gap parallel to the width direction is the vertical horizontal gap[1-2].

(3) The amount of the gap perpendicular to the width direction is the same as the amount of the transverse gap; the total number of the longitudinal slits are equal to the sum of the gap amount and the vertical gap amount which is parallel to the width direction[3].

In order to studying the influence of slot width on water saturation of two-phase flow in medium gap electric field case, this paper designs three kinds of single slit models with different widths to research the influence of external electric field on the water saturation of the two phase flow in the slit media.

2. Theoretical analysis

First, before the results of the finite element calculation and analysis, we discuss the relationship between the physical two-phase flow mathematical model under the external electric field.

Permeability equation of water - phase interaction of oil - water two - phase seepage under external electric field is the formula(1), that is

$$v_w = -\frac{kk_{rw}}{\mu_w}\frac{dp_w}{dx} + \frac{\varepsilon\xi_{sw}\phi k_{rw}}{\tau'\mu_w}\frac{d\Phi}{dx} \tag{1}$$

Ignoring the changes in the nature of the rocks caused by the electric field, such as porosity, absolute permeability, etc. Pore structure and fluid properties determine the relative permeability of oil-water two-phase[4-5]. Only from the Darcy seepage mechanics law, oil-water two-phase seepage of the water phase motion under the action of the electric field equation can be written as[6-7]

$$v_w = -\frac{kk_{rw}^*}{\mu_w}\frac{dp_w}{dx} \tag{2}$$

In equation (2), k_{rw}^* represents the relative permeability of the water phase obtained from the seepage mechanism in the presence of an external electric field.

If the equation(1) and (2) are equal to each other, then

$$-\frac{kk_{rw}^*}{\mu_w}\frac{dp_w}{dx} = -\frac{kk_{rw}}{\mu_w}\frac{dp_w}{dx} + \frac{\varepsilon\xi_{sw}\phi k_{rw}}{\tau'\mu_w}\frac{d\Phi}{dx} \tag{3}$$

Simplified by the above formula, it can be obtained

$$k_{rw}^* = k_{rw}\left(1 - \frac{\varepsilon\xi_{sw}\phi}{\tau' k}\frac{d\Phi}{dx}\right) \tag{4}$$

The presence of Zeta potential in the solid-liquid surface is: $\xi_{sw} < 0$; While the external electric field is opposite to the voltage drop, that is $d\Phi/dx < 0$; So then

$$\frac{k_{rw}^*}{k_{rw}} = \left(1 - \frac{\varepsilon\xi_{sw}\phi}{\tau' k}\frac{d\Phi}{dx}\right) < 1, \quad \text{so, } k_{rw}^* < k_{rw} \tag{5}$$

The measured permeability curve can be fitted to the relative permeability of the oil-water phase

$$k_{ro} = \alpha_1 (1 - S_{wD})^{\beta_1} \tag{6}$$

$$k_{rw} = \alpha_2 S_{wD}^{\beta_2} \tag{7}$$

And the normalized saturation S_{wD} in equation (6) is

$$S_{wD} = \frac{S_w - S_{wi}}{1 - S_{or} - S_{wi}} \tag{8}$$

From the type (7) sort out

$$S_{wD} = \left(\frac{1}{\alpha_2}k_{rw}\right)^{\frac{1}{\beta_2}} \tag{9}$$

Combine the type (9) and (8) to obtain a normalized water saturation S_{wD}

$$S_{wD} = \frac{S_w - S_{wi}}{1 - S_{or} - S_{wi}} = \left(\frac{1}{\alpha_2}k_{rw}\right)^{\frac{1}{\beta_2}} \tag{10}$$

The equation for normalizing the saturation S_{wD}^* in the presence of an external electric field is shown below

$$S_{wD}^* = \frac{S_w^* - S_{wi}}{1 - S_{or} - S_{wi}} = \left(\frac{1}{\alpha_2}k_{rw}^*\right)^{\frac{1}{\beta_2}} \tag{11}$$

Equations (5), (10) are associated with (11), and simplification is available

$$\frac{S_{wD}^*}{S_{wD}}=\frac{S_w^*-S_{wi}}{S_w-S_{wi}}=\left(1-\frac{\varepsilon\xi_{sw}\phi}{\tau' k}\frac{(d\Phi/dx)}{(dp/dx)}\right)^{\frac{1}{\beta_2}} \tag{12}$$

While the Zeta potential exists on the solid-liquid surface is: $\xi_{sw}<0$; And the direction of the applied electric field is opposite to the voltage drop direction, So there is $\frac{\varepsilon\xi_{sw}\phi}{\tau' k}\frac{(d\Phi/dx)}{(dp/dx)}>0$, By the type(12) available

$$\frac{S_{wD}^*}{S_{wD}}=\frac{S_w^*-S_{wi}}{S_w-S_{wi}}=\left(1-\frac{\varepsilon\xi_{sw}\phi}{\tau' k}\frac{(d\Phi/dx)}{(dp/dx)}\right)^{\frac{1}{\beta_2}}<1 \tag{13}$$

Also

$$S_{wD}^*<S_{wD} \text{ or } S_w^*<S_w \tag{14}$$

Therefore, in the absence of an electric field, the water saturation is greater than it in the case of applying an electric field.

According to equation (6), the expression of the external electric field relative to the oil permeability can be written as follows

$$k_{ro}=\alpha_1\left(1-S_{wD}^*\right)^{\beta_1} \tag{15}$$

The formula (15) is divided by the formula (6), and the results obtained by the reference formula (14) are as follows

$$\frac{k_{ro}^*}{k_{ro}}=\left(\frac{1-S_{wD}^*}{1-S_{wD}}\right)^{\beta_1}>1\text{, that is } k_{ro}^*>k_{ro} \tag{16}$$

According to the above theoretical analysis, the reference equations (5) and (16) obtained the conclusion: When the pressure drop direction is opposite to the direction of the external electric field, the relative permeability of the water phase decreases and the relative permeability of the oil phase increases; In the presence of an external electric field, the water saturation has a change in the relative permeability of the water phase on the seepage curve, which is reduced and the relative permeability change of the oil phase is opposite and increased.

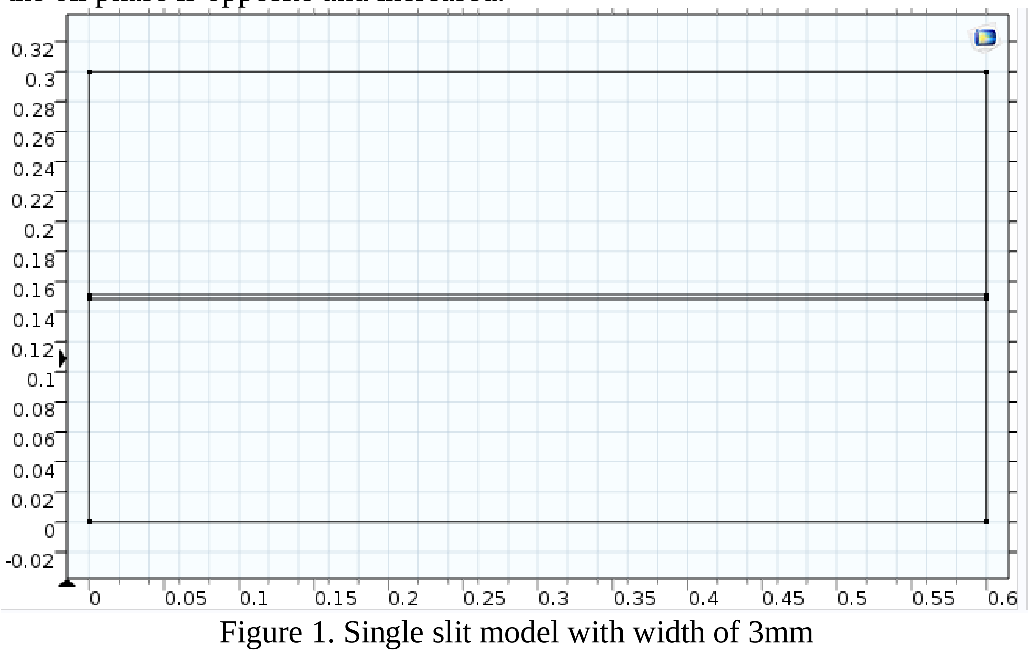

Figure 1. Single slit model with width of 3mm

Figure 2, Single slit model with width of 9mm

Figure 3. Single slit model with width of 15mm

3. Simulation analysis of different gap width models under DC electric field

The following are three different structural models of the gap width:

Figure1 is a single slit model with module length of 0.6m, width of 0.3m, height of 0.3m and width of 3mm, Figure2 is a single slit model with module length of 0.6m, width of 0.3m, height of 0.3m and width of 9mm, Figure3 is a single slit model with module length of 0.6m, width of 0.3m, height of 0.3m and width of 15mm.

4. Conclusion

When the pressure and the external electric field are fixed, the narrower the gap width is, the lower the water saturation of the gap medium is, that is to say, the water permeability decreases and the permeability increases.Only when the pressure is constant, the water saturation in different gap width modules decreases as the external electric field increases, and the narrower the width is, the lower the water saturation is in the model, the effect of the external electric field will be more obvious.

With the increase of the external electric field, the water saturation in the different slot width modules decreases gradually.The external electric field is gradually increased from 0V to 240V, and in this range, when the applied electric field reaches 160V, the water saturation in the different slit width model does not decrease, and tends to a fixed value.Even if the applied electric field continues increasing, the water saturation in the different slot width modules remains the same. At this time, the water saturation reaches the minimum value and the oil saturation reaches the maximum under different gap width modules with the applied electric field.It is determined that 160V is the optimum electric potential of the external electric field.

Acknowledgments

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