The choice of the correlating function of capillary pressure curves under conditions of reservoirs in Western Siberia

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Abstract. The article considers the approximation of capillary pressure curves of productive formations in Western Siberia. The relationship between the correlating functions of capillary pressure curves is shown: the Leverett J-function and the Brooks-Corey function. In this case, the Brooks-Corey function is the same Leverett function but used for water saturation of the effective part of the void space (reduced water saturation). The authors recommend choosing a correlation function for a given reservoir, depending on the tightness of the correlation between capillary pressure and volumetric or reduced water saturation. In this case, the Leverett function should be preferred, since it depends only on two parameters (permeability and porosity).

1. Introduction
Any operational facility is characterized by the following basic parameters: porosity, permeability, and residual water saturation [1–4].

The analysis shows that capillary pressure curves of core samples relate all these basic parameters of reservoir formations. Therefore, the study of capillary characteristics, as a rule, is a common laboratory analysis, as well as the determination of reservoir properties of productive formations [5].

According to capillarimetry data of a particular field, the following main tasks are solved:

- quantitative assessment of distribution of pore channels in size;
- construction of curves of relative permeabilities for oil and water;
- distribution of water saturation along the height of oil reservoir.

2. Methods and materials
In this article, the results of laboratory studies of core samples were used. The relationship between the correlating functions of capillary pressure curves is investigated: the Leverett J-function and the Brooks-Corey function.
Currently, there are a number of mathematical models that allow approximate the entire set of capillary curves and transform them into the formula for the capillary pressure of water saturation.

The most popular among them are the Leverett J-function and the Brooks-Corey model [6].

In the first case, the correlation function J is used, taking into account physical properties of rock and liquids [6]:

\[ J(K_w) = \frac{P_k}{\sigma \cos \theta} \sqrt{\frac{K_{np}}{K_n}}, \]

(1)

where \( P_k \) is capillary pressure; \( \sigma \) is surface tension; \( K_{np} \) − permeability; \( K_n \) − porosity; \( K_w \) − water saturation.

The dependence of the J-function on the current water saturation, as a rule, has the following form:

\[ J = A \cdot K_w^{-n}, \]

(2)

where A and n are fixed coefficients for a given reservoir.

Many researchers believe that the Leverett J-function does not always allow satisfactory approximation of capillary pressure curves of reservoir layers with pronounced variability in the structure of void space.

In this regard, when modeling capillary pressure curves, it is considered more preferable to use the Brooks-Corey function [7–11]:

\[ K_B = K_{wo} + (1 - K_{wo}) \left( \frac{P_n}{P_k} \right)^\frac{1}{n}, \]

(3)

where \( K_{wo} \) is the residual water saturation; \( P_n \) − initial (inlet capillary pressure); \( n \) is the coefficient of curvature of the capillary curves.

Compare the Leverett J-function with the model proposed by researchers Brooks and Corey.

To do this, we equate the right parts of formulas (1) and (2) and obtain the expression for capillary pressure:

\[ \frac{P_k}{\sigma \cos \theta} \sqrt{\frac{K_{np}}{K_n}} = A \cdot K_B^{-n}. \]

From here we have:

\[ P_k = \frac{A \sigma \cos \theta}{\sqrt{K_{np}/K_n}} K_B^{-n}. \]

Further, let the water saturation coefficient \( K_w \) tends to unity, then

\[ P_k \rightarrow \frac{A \sigma \cos \theta}{\sqrt{K_{np}/K_n}} = P_n, \]

where \( P_n \) − initial (input) capillary pressure.

Then we finally get a simple formula for capillary pressure:

\[ P_k = P_n K_B^{-n}. \]

Hence

\[ K_B = \left( \frac{P_n}{P_k} \right)^\frac{1}{n}. \]

Now I get into the Brooks-Corey formula. First, we transform the formula (3) in the following form:

\[ \frac{K_B - K_{wo}}{1 - K_{wo}} = \left( \frac{P_n}{P_k} \right)^\frac{1}{n}. \]

(4)

Further we denote

\[ K_B^* = \frac{K_B - K_{wo}}{1 - K_{wo}}. \]

Then we finally get

\[ K_B^* = \left( \frac{P_n}{P_k} \right)^\frac{1}{n}. \]

(5)
where \( K_v^* \) is the reduced water saturation of reservoir void space, i.e. water saturation of the effective volume of pore channels.

3. Results

Thus, if you use the reduced amount of void space, then the Brooks-Corey model automatically goes into the Leverett model.

In other words, the Brooks-Corey model takes into account the fact that the residual water does not participate in fluid movement and therefore is more justified [12, 13].

Figure 1 shows the results of comparing the J-function with the volumetric water saturation (a) and reduced water saturation (b) for the terrigenous reservoir \( AB_1^3 \) of Las-Eganskoe field in Western Siberia.

The review of the graphs shows that this parameter is closely related to the reduced water saturation, while its relationship with the volumetric water saturation is rather weak.

Figure 2 shows similar dependencies for the productive reservoir \( IOB_1^3 \) of Povkhovskoe field.

The analysis of the graphs shows that the J-function is quite closely related both to the volumetric reduced water saturation (Figure 2, a) and to the volumetric water saturation (Figure 2, b)

Thus, in some layers, a capillary pressure curve is well described by the Leverett J-function, and in others – by the Brooks-Corey model.

In the first case, the rock is probably relatively homogeneous; and residual water, mainly, is capillary-retained and film adsorbed on the surface of the pore channels, while the clay content is small and scattered in the void space volume.

In the second case, the rock contains a large amount of bound water held by clay particles (layered clay), while even at high pressures, clay remains in the clay layers.

**Figure 1.** The dependence of the J-function: a – from the volumetric water saturation; b – from the reduced water saturation.

It should be noted that the Leverett J-function is determined by two parameters: absolute permeability and open porosity.

The Brooks-Corey model is described by three parameters: in addition to the above two parameters, one more parameter is added: residual water saturation, which is a drawback of this model.
Figure 2. The dependence of the $J$-function: $a$ – from the volumetric water saturation; $b$ – from the reduced water saturation

4. Conclusion
1. The $J$-function and the Brooks-Corey function have the same meaning. However, the first describes the entire void space of formation, and the second – only the effective part (reduced water saturation).

2. When choosing a correlating function for a given formation, it is necessary:
   a) according to laboratory studies, build two dependencies: capillary pressure and current water saturation, and capillary pressure and reduced water saturation
   b) choose a schedule that is characterized by a greater tightness of communication (less scatter of points). With the same scatter of points, the Leverett function should be preferred, since it depends on only two parameters (permeability and porosity).

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