Analysis and Application of Capillary Pressure Data

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Abstract. The article proposes a method for determining the water saturation of oil and gas reservoirs based on the use of typical capillary pressure curves. There is a relationship between capillary pressure and water saturation, which consists in the fact that residual water is retained in the pore, hydrocarbon-saturated space of the reservoir due to capillary forces. Based on the results of a laboratory study of 75 core samples, typical capillary pressure curves were constructed. Using these curves, it is possible to determine such reservoir parameters as: residual water saturation, water saturation at a given distance from the OWC and others. Knowledge of these parameters will improve the control and regulation of the development of oil and gas fields.

1. Introduction
Typical curves are used to plot the capillary pressure curve for the desired permeability as follows:
1. record the values of capillary pressure and read the corresponding values of water saturation;
2. the obtained data are marked on the graph of the dependence of permeability on water saturation and a straight trend line is drawn for each value of the capillary pressure;
3. For the required permeability, read the corresponding water saturation values and build the capillary pressure curve.

According to the obtained capillary pressure curve, the residual water saturation of the formation medium with the required permeability is determined as the water saturation value corresponding to the upper, almost vertical section of the curve, where, with large changes in capillary pressure, the change in water saturation is insignificant. For example, the residual water saturation of the reservoir medium with permeability \( k = 950 \text{ mD} \) is about 17.6% of the pore volume.
2. Methods
Capillary pressure at an arbitrary point of the reservoir medium depends on its position relative to the oil-water contact (OWC, relative to the horizontal boundary below which there is a purely water zone, and above it, the water-oil zone begins):

\[ P_c = \frac{\sigma_w}{\sigma_{ow}}(\gamma_w - \gamma_o)h \]  

where \( P_c \) – capillary pressure, \( Pa \); \( \sigma_{ow} \) - interfacial tension "oil-water" in reservoir conditions, \( N/m \); \( \sigma_w \) - surface tension "air - water" in laboratory conditions, \( N/m \); \( \gamma_w \) - specific weight of formation water, \( N/m^3 \); \( \gamma_o \) - specific weight of oil in reservoir conditions, \( N/m^3 \); \( h \) - vertical distance from the OWC to the point, \( m \).

In deriving these equations, the following assumptions were made:

a) laboratory cleaning and other procedures did not change the characteristics of the breed;
b) the rock is 100% wettable with water;
c) the radii of curvature of the fluid surface in laboratory and reservoir conditions are equal;
d) the reservoir was initially saturated with water, which was subsequently displaced by hydrocarbon; the displacement of water was incomplete: part of it is retained by capillary forces;
e) in the opened formation, the amount of water and oil corresponds to the balance of gravitational and capillary forces.

By calculating the ratio of the capillary pressure scales and the distance to the oil-water contact, it is possible to determine the water saturation of the pore medium at any distance from the OWC.

3. Results and discussion
As an example, let's build a graph of the dependence of capillary pressure on water saturation for permeability \( k = 155 \text{ mD} \), and from it we determine:
a) residual water saturation at a given permeability;
b) coefficient of proportionality between the distance to the OWC level and capillary pressure;
c) water saturation at a distance of 45\( m \) above the OWC.

![Figure 1. Typical capillary pressure curves for sandstone.](image)
The following data are known:
interfacial tension "oil - water" in reservoir conditions $3.3 \times 10^3$ N/m;
surface tension "air - water" in laboratory conditions $7.1 \times 10^3$ N/m;
specific weight of formation water $10334.65$ kg/m$^3$;
specific weight of oil in reservoir conditions $7119.42$ kg/m$^3$.

Using typical curves (Figure 1), we construct a capillary pressure curve for the required permeability:

1. we fix the values of capillary pressure, for example, 0.525 MPa, 0.35 MPa, 0.175 MPa, 0.07 MPa, 0.035 MPa, and read the corresponding values of water saturation (table 1);

### Table 1. Capillary pressure data for fixed permeability values, obtained from typical curves.

| permeability $k$, mD | capillary pressure $P_c$, MPa |
|----------------------|-----------------------------|
|                      | 0.525 | 0.35 | 0.175 | 0.07 | 0.035 |
| 950                  | 14    | 16.5 | 22    | 30   | 39    |
| 300                  | 22.5  | 25.5 | 34    | 45.5 | 56    |
| 50                   | 30    | 36   | 47    | 61.5 | 78    |
| 25                   | 44.5  | 47.5 | 59    | 71.5 | 83    |
| 10                   | 50.5  | 53   | 63.5  | 81   | 92    |

2. we mark the obtained data on the graph of the dependence of permeability on water saturation and draw a straight trend line for each value of the capillary pressure (Figure 2);

**Figure 2.** Dependence of permeability on water saturation at a fixed capillary pressure.
3. for permeability \( k = 155 \text{ mD} \), we read the corresponding values of water saturation (figure 3, table 2) and build the capillary pressure curve (figure 4).

![Graph showing capillary pressure vs water saturation for different permeabilities.]

**Figure 3.** Determination of the dependence of capillary pressure on water saturation at permeability \( k = 155 \text{ mD} \).

**Table 2.** Capillary pressure and water saturation data for permeability \( k = 155 \text{ mD} \), determined from the graphs in Figure 3.

| capillary pressure \( P_c \), MPa | water saturation \( S_w \), % |
|----------------------------------|-----------------------------|
| 0,525                            | 27                          |
| 0,35                             | 33                          |
| 0,135                            | 41                          |
| 0,07                             | 51                          |
| 0,035                            | 61,5                        |
Figure 4. Capillary pressure curve for sandstone with permeability \( k = 155 \) mD.

We calculate the coefficient of the dependence of capillary pressure on the distance to the OWC:

\[
P_c = \frac{\sigma_w}{\sigma_{ow}} (\gamma_w - \gamma_o) h = \frac{71 \cdot 10^{-3} N/m}{33 \cdot 10^{-3} N/m} \cdot (10334,65 N/m^3 - 7119,42 N/m^3) \cdot h = 6917,6 \ h
\]

4. Conclusion

The ratio of the scales of capillary pressure and the distance to the OWC makes it possible to determine the water saturation at a distance of 45 m above the OWC according to the graph shown in Figure 4: \( S_w = 39,6\% \).

Residual water saturation of the reservoir medium with permeability \( k = 155 \) mD is about 29% of the pore volume.

The coefficient of the dependence of capillary pressure on the distance to the OWC was also calculated, which makes it possible to determine the water saturation of the reservoir at a given distance.

5. References

[1] Nasyrov I I, Mamchistova E I, Nasyrova A I 2018 Evaluation Of Well Interference By Correlation Analysis IOP Conference Series: Earth and Environmental Science 2 The State, Trends and Problems of Development of the Oil and Gas Potential of Western Siberia C 012018

[2] Korotenko V A, Grachev S I, Kushakova N P, Leontiev S A, Zaboeva M I, Aleksandrov M A 2018 On Modeling Of Non-stationary Two-phase Filtration IOP Conference Series: Earth and Environmental Science 2 The State, Trends and Problems of Development of the Oil and Gas Potential of Western Siberia C 012016
[3] Levitina E E, Pyankova E M, Lesnoi A N 2010 Determination of Reservoir Properties on the Basis of Analysis of Pressure Measurements by Deep Sensors Automatizatsiya, telemehanizatsiya isvyaz v nefyanoipromyshlennosti 3 29-33

[4] Levitina E E 2010 Influence Of Density Of Gas-liquid Mixture At The Pressure In The Well News of higher educational institutions. Oil and gas 1 35-40

[5] Mamistova E I, Nazarova N V, Zaboeva M I 2016 Analysis Of Linear Programming Methods In The Organization Of Repair Work On Wells In The Conditions Of Uncertainty And Risk Academic journal of Western Siberia Vol 12 1(62) 12-14

[6] Karnaukhov M L, Levitina E E, Gafinet A Z, Pyankova E M 2010 Interpretation Of The Curves Reducing Pressure Recorded At Start-up The Well Work The Territory Of Oil And Gas 4 40-43

[7] Zakirov N N, Mulyavin S F, Sarancha A V, Yudakov A N 2017 Results of Indicator Studies on Facility in Kholmistoye Field IOP Conference Series: Earth and Environmental Science "Innovations and Prospects of Development of Mining Machinery and Electrical Engineering - Mining Ecology" 87 042027

[8] Levitin R E, Tryascin R A 2016 Determining Fuel Losses in Storage Tanks Based on Factual Saturation Pressures IOP Conf. Series: Materials Science and Engineering "International Scientific-Practical Conf. of Students, Graduate Students and Young Scientists "Transport and Storage of Hydrocarbons" 154 012022

[9] Sarancha A V, Shuldikova N S 2017 Results of Research and Commercial Production of Shale Oil in Bashenov Formationon Ai-Pimskoe Field IOP Conf. Series: Earth and Environmental Science "Innovations and Prospects of Development of Mining Machinery and Electrical Engineering - Mining Ecology" 87 042018

[10] Evstrakhina E E, Soloviev O I, Rozhkov I V 2008 Diagnostic of Results of Hydro-Dynamical Studies and Determination of the Information Content of Pressure Recovery Curve New technologies for the fuel and energy complex of Western Siberia 3 377-383