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# CONTRIBUTION TO THE STUDY OF MOVEMENT CAPILLARY MIGRATION OF OIL AND WATER

# *CONTRIBUȚII LA STUDIUL MIGRAȚIEI CAPILARE ASCENDENTE A PETROLULUI ȘI APEI*

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***Abstract:*** *The upward migration of water and oil (exclusively under the action of capillary forces in fine channels of sedimentary rocks) is an area of theoretical and experimental investigation. Its knowledge allows the scientific explanation of the process of migration and accumulation of oil and water under the action of capillarity and from it derives more realistic guidelines in the geological investigation for the discovery of new hydrocarbon reservoirs. This paper presents the result of the personal experimental researches about the ascendency movement of the oil and water under the capillary pressure action. One show migratory heights and speeds, different for oil and water, as the oil fractionate in the time of the capillary movement.*

***Keywords****:* rock, saturation, capillary ascent, migration speed.

**Rezumat:** *Migrația ascendentă a apei și petrolului (exclusiv sub acțiunea forțelor capilare în canalele fine ale rocilor sedimentare) este un domeniu de investigație teoretică și experimentală. Cunoștințele sale permit explicarea științifică a procesului de migrare și acumulare a petrolului și apei sub acțiunea capilarității și din aceasta derivă linii directoare mai realiste în investigația geologică pentru descoperirea de noi rezervoare de hidrocarburi. Această lucrare prezintă rezultatul cercetărilor experimentale permanente despre mișcarea de ascensiune a uleiului și apei sub acțiunea presiunii capilare. Unul arată înălțimi și viteze de migrare, diferite pentru petrol și apă, deoarece uleiul se fracționează în timpul mișcării capilare.*

**Cuvinte cheie:** rocă, saturație, ascensiune capilară, viteza de migrație

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## 1. Introduction

The upward migration of water and oil, solely under the action of capillary forces in fine channels of sedimentary rocks, is an area of theoretical and experimental investigation.

Its knowledge allows the scientific explanation of the process of migration and accumulation of oil and water under the action of capillarity, and from it derives more realistic guidelines in the geological investigation for the discovery of hydrocarbon deposits.

Pursuing the clarification of some aspects of this problem, the author's were concerned in a first stage with carrying out an experiment to determine the maximum capillary ascent and capillary migration speed, separately for water and for oil. For this purpose, glass tubes (capillarimeters) with an inner diameter of about 22 mm and a length of over 1 m were used, which were filled with siliceous Oligocene sand, very fine and very well compacted, in order to be sure that the spaces free between the rock particles do not exceed capillary dimensions (table 1 and table 2). Capillameters closed at both ends were fixed in a vertical position, so that the lower end of one of the tubes was placed in contact with a vessel containing water, and the lower end of the other was placed in contact with a vessel containing oil.

## 2. RESULTS AND DISCUSSIONS

From the examination of the observational data, it follows that the two fluids behave differently in terms of the maximum height of capillary ascent, under the same conditions of porosity and capillary channel dimensions: the maximum height for water was about 248 cm reached by water after a time interval of 196 days, and for oil the maximum height was about 118 cm reached after an interval of 128 days from the start of migration. In this interval, the water had already risen to about 225 cm, which is almost double the maximum capillary ascent of the oil [1].

Calculations regarding the speed of capillary ascent show an important variation of it depending on the height at which the filtration is carried out (tables 3 and 4) and (figure 2).

The capillary rise speed decreases sharply with the increase of the filtration height, both for water and for oil. But in the case of oil, from the beginning, the ascent speed is lower than the water speed and this is maintained in the interval up to 115 cm capillary height with $10^{-1}$ cm/s following the water speed [2].

Therefore, on this interval the speed of capillary ascent of oil is about 10 times lower than the speed of water. From (figure 1) it follows that at height greater than 100 – 120 cm, the capillary ascent velocities of the two fluids differ more.

Table 1 – **Capillary rise of water in capillarimeter I**

| Day | Month | Time | Capillary rise (cm) |
|---|---|---|---|
| 31 | III | 11 h | 0 |
| 31 | III | 11 h | 5 |
| 31 | III | 11 h | 8 |
| 31 | III | 11 h | 13,5 |
| 31 | III | 12 h | 19,5 |
| 31 | III | 16 h | 39,5 |
| 31 | III | 19 h | 48 |
| 1 | IV | 7h 10’ | 62,5 |
| 2 | IV | 8h 10’ | 79 |
| 3 | IV | 11h | 89 |
| 4 | IV | 7h 0’ | 94,3 |
| 6 | IV | 8h 0’ | 103 |
| 15 | IV | 9h 0’ | 113,4 |
| 20 | IV | 14h | 131,5 |
| 30 | IV | 15h | 143,5 |
| 15 | IV | 7h 20’ | 161,5 |
| 30 | V | 8h 15’ | 180 |
| 30 | V | 9h 0’ | 193 |
| 5 | VI | 13h | 213 |
| 12 | X | 8h 0’ | 226,5 |
| 16 | XI | 12h | 248 |

The capillary migration velocity of oil as an absolute value is at most $10^{-3}$ cm/sec. and of water $10^{-2}$ cm/sec. so it decreases with height.

This leads to the conclusion that in natural capillary media oil and water cannot migrate together when they form separate phases, but water moves ahead of oil given its higher velocity (table 3 and table 4) [3].

*Table 2* –**Capillary rise of oil in capillarimeter II**

| Day | Month | Time | Capillary rise (cm) |
|---|---|---|---|
| 2 | II | 8h 0’ | 0 |
| 2 | II | 8h 5’ | 1,5 |
| 2 | II | 8h 10’ | 2,3 |
| 2 | II | 8h 20’ | 3,2 |

*Table 2* (continued)

| Day | Month | Time | Capillary rise (cm) |
|---|---|---|---|
| 2 | II | 9h 0’ | 5,6 |
| 2 | II | 10h | 9,3 |
| 2 | II | 12h | 12,3 |
| 2 | II | 15h 0’ | 15,8 |
| 2 | II | 20h 0’ | 20,9 |
| 3 | II | 7h 0’ | 29 |
| 3 | II | 19h | 34,5 |
| 4 | II | 19h | 42 |
| 7 | II | 17h 0’ | 55,2 |
| 10 | II | 8h 0’ | 63 |
| 16 | II | 8h 0’ | 74,8 |
| 25 | II | 8h 0’ | 85 |
| 7 | III | 8h 0’ | 93,3 |
| 27 | III | 8h 0’ | 103 |
| 29 | IV | 8h 0’ | 111,2 |
| 9 | IV | 8h 0’ | 117,8 |
| 11 | VII | 8h 0’ | 118 |
| 10 | VIII | 8h 0’ | 118 |

The careful follow-up of the ascending capillary migration reveals some interesting phenomena, thus it is found that the ascent of both fluids is carried out preferentially on certain sections of the section, and the level of the fluid in the rock does not have a flat shape with a surface that is more irregular the higher the height on which migration occurred.

At the height above 100 cm, the deviation of the liquid from a horizontal plane is 1 – 2 cm for water and 2 – 3 cm for oil. In this case the oil level has a more irregular shape than the water level (figures 1 and 2).

*Table 3* – **Capillary rise rate for water**

| Filtration interval (cm) | Filtration speed (cm/s) |
|---|---|
| 0 – 2 | $3,8 \cdot 10^{-3}$ |
| 2 – 6 | $1,1 \cdot 10^{-4}$ |
| 11 – 15 | $4,1 \cdot 10^{-4}$ |
| 15 - 20 | $3 \cdot 10^{-4}$ |
| 20 – 30 | $1,8 \cdot 10^{-4}$ |
| 30 – 40 | $1 \cdot 10^{-4}$ |
| 40 – 55 | $1,1 \cdot 10^{-5}$ |
| 75 – 85 | $1,3 \cdot 10^{-5}$ |
| 99 – 110 | $3,8 \cdot 10^{-6}$ |
| 110 – 115 | $1,8 \cdot 10^{-6}$ |

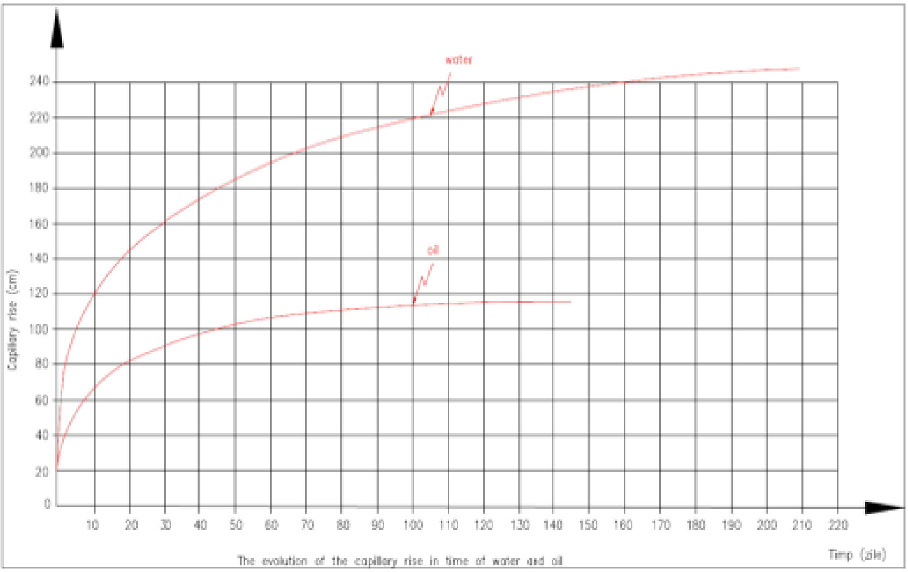


**Figure 1 –** The evolution on the capillary rise in time of water and oil

*Table 4* – **Capillary rise rate for oil**

| **Filtration interval (cm)** | **Filtration speed (cm/s)** |
|---|---|
| 0 – 5 | $1{,}7 \cdot 10^{-2}$ |
| 5 – 8 | $1 \cdot 10^{-2}$ |
| 8 – 10 | $7 \cdot 10^{-3}$ |
| 10 – 13 | $3{,}9 \cdot 10^{-3}$ |
| 13 – 20 | $3{,}3 \cdot 10^{-3}$ |
| 40 – 48 | $7{,}2 \cdot 10^{-4}$ |
| 79 – 83 | $1{,}2 \cdot 10^{-4}$ |
| 94 – 99 | $5 \cdot 10^{-5}$ |
| 107 – 110 | $3{,}6 \cdot 10^{-5}$ |
| 113 – 115 | $2 \cdot 10^{-5}$ |

Another observation regarding oil is related to the fact that from the capillary migration height of 10 cm the oil begins to fractionate according to its chemical components: in the lower part of the column the heavier and more viscous fractions remain, and in the upper part the lighter (gasoline) fractions pass.

Continuing the filtration until reaching the maximum capillary rise, the separation of the two fractions becomes more and more accentuated so that finally the lower column with the heavy fraction remains constant at the level of 50 cm, while above it is the light fraction whose level rises to 118 cm.

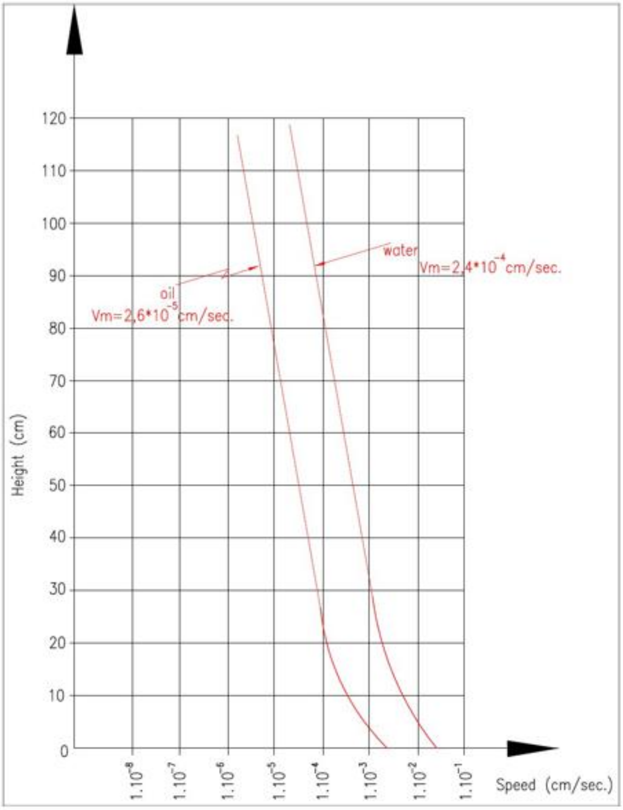


**Figure 2 –** The correction between the height and cappilary ascent speed of water and oil

This separation is not driven by gravity but by the forces of adhesion to the mineral grains of the rock, which are greater for the heavy fraction compared to the light fraction.

The fact that the rise height of the light fraction increases with time until reaching a maximum value shows that the heavy fraction at the bottom of the column cannot clog and create a barrier in front of the mobile light fraction.

In most hydrocarbon reservoir's, the reservoir rock was completely saturated with water before hydrocarbon migration (primary migration).

It is assumed that the lightest hydrocarbons migrate until reaching the hydrostatic and hydrodynamic equilibrium by displacing the water starting from the lowest areas of the structure.

The hydrocarbons will not displace all the water initially existing in the pore space. Thus, the pores of the reservoir rock can contain up to three fluid phases, i.e.: crude oil, gas and water. Figure 3 determines:

$S_0 \approx 0$ in the gas zone;
$S_0 \geq 15$ % in the oil area;
$0 \leq S_0 \leq S_0R$.

where: $S_0R$ – residual saturation in crude oil.

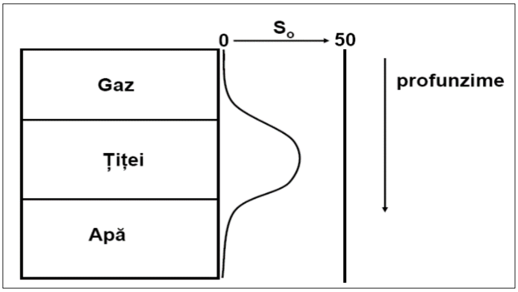


**Figure 3 –** Representation of saturation in crude oil.

The connection between capillary pressure and saturation in fluids is represented in (figure 4):

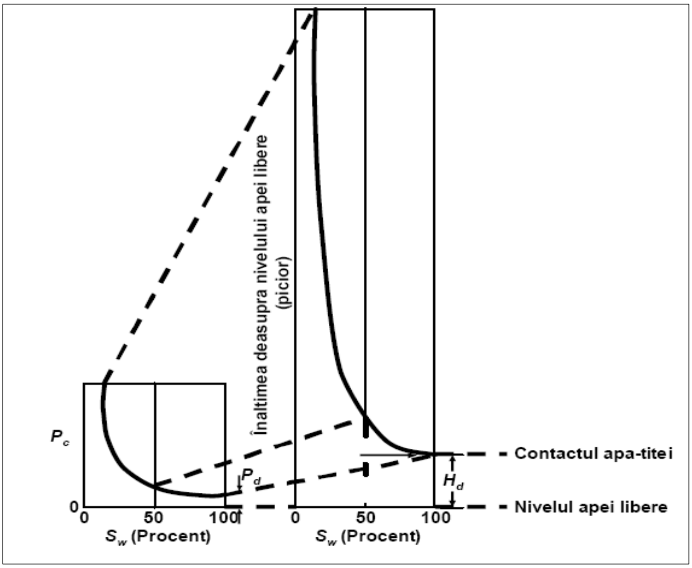


**Figure 4 –** The connection between capillary pressure and saturation in fluids.

For homogeneous sands, the fluid saturation of the deposit is a function of the height above the FWL level, according to the relationship:

$$P_c = p_o - p_w = \frac{\Delta h}{144}(\rho_w - \rho_o) \tag{1.1}$$

Distribution of fluids in oil reservoir's (figure 5):

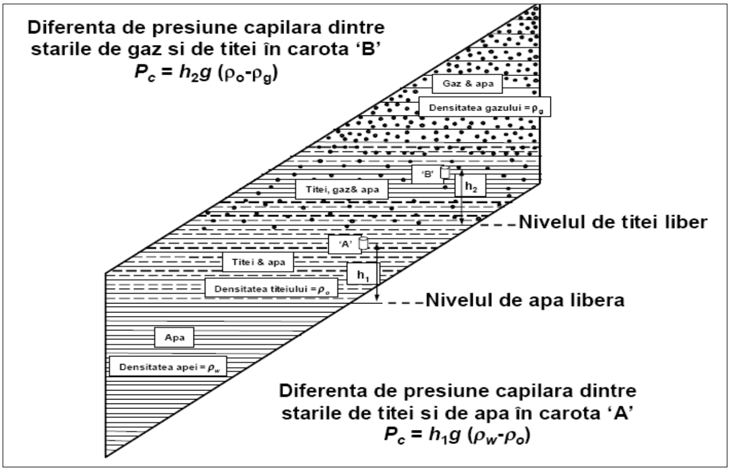


**Figure 5 –** The connection between capillary pressure and saturation in fluids.

The FWL level is the level at which the capillary pressure is 0, i.e., the pressures in the two phases are equal.

Above the FWL level, crude oil and water coexist. Above this level, another level known as the crude water contact (WOC) can be identified.

Below the WOC, only water can be produced. Above the WOC level (limit), both phases coexist. At a certain point above the WOC, the water will reach an irreducible value and will no longer be mobile (free). In the same way, a level with maximum saturation in crude oil (FOL=free oil level) and a crude gas contact (OGC) can be identified (figure 6).

This complex diagram shows the distribution of fluids within a reservoir. Gases and crude oil can be easily distinguished from water.

A crude water transition zone of about 7 feet can be identified in the figure above.

The thickness of the transition zone is a function of the density difference between the two fluids. The transition zone will be smaller at a large density difference and larger at a small density difference. This relationship is obvious as a result of the relationship between capillary pressure and the height above the free water level (FWL).

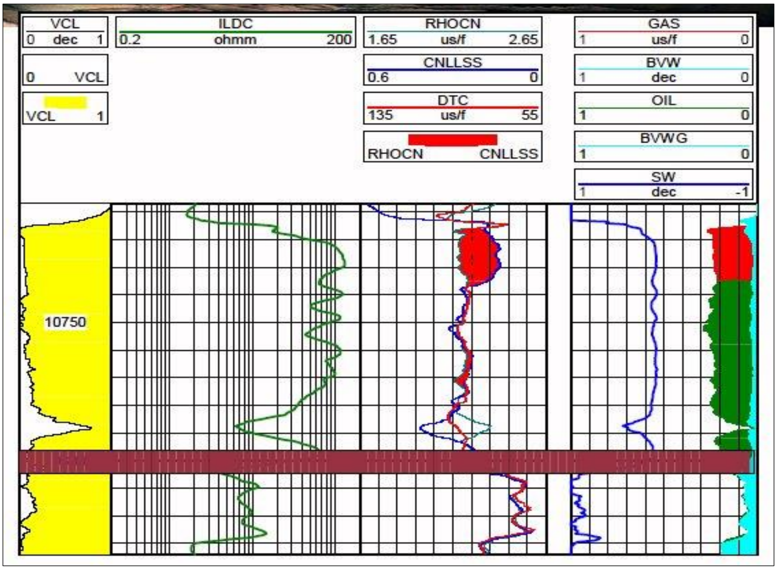


**Figure 6 –** The connection between capillary pressure and saturation in fluids.

***Case study:***

***Case study 1)***

Calculate the height of the water-crude transition zone for two cases:
A) heavy oil :59.3 $lb_m/ft^3$
B) light oil :43.7 $lb_m/ft^3$

*Input data:*

Capillary pressure = 5 psia
Water density = 66.5 $lb_m/ft^3$

*Solving:*

$$A) P_c = \frac{\Delta h}{144}(\rho_w - \rho_o) = \frac{\Delta h}{144}(66.5 - 59.3) = 5 \Rightarrow \Delta h = 100m \qquad (1.2)$$

$$B) P_c = \frac{\Delta h}{144}(\rho_w - \rho_o) = \frac{\Delta h}{144}(66.5 - 43.7) = 5 \Rightarrow \Delta h = 31.57m \qquad (1.3)$$

***Case study 2)***

Calculate the height at which the oil-water contact is above the free water level.

Calculate the transition zone:

*Input data:*

Oil density :45.7 lb/cft
Water density : 62.43 lb/cft
Lanoratory data: (Table 5)

*Table 5* – **Laboratory data**

| Saturation in Hg | Capillary pressure, psi |
|---|---|
| 0 | 234 |
| 0.158 | 281 |
| 0.375 | 324 |
| 0.533 | 379 |
| 0.731 | 576 |
| 0.838 | 1125 |
| 0.885 | 3000 |

Information from the reservoir:

$$\sigma_{res} = 25\, {}^{dynes}/_{cm} = 30^{\circ} \quad (1.4)$$

Laboratory information:

$$\sigma_{res} = 100\, {}^{dynes}/_{cm} = 140^{\circ} \quad (1.5)$$

In order to be able to transform the capillary pressure data measured in the laboratory into capillary pressure data under deposit conditions, the following relationship will be used:

$$Pc_{res} = \left| \frac{\sigma_{res} \cos\theta_{res}}{\sigma_{lab} \cos\theta lab} Pc_{lab} \right| \Rightarrow Pc_{res1} = \frac{25 \times 0.86}{100 \times 0.766} Pc_{lab} = 66.13 \quad (1.6)$$

Applying the same relationship for the rest of the measurements performed in the laboratory, the data in Table 6 will be obtained .

$$OWC_{\text{h deasupra FWL}} = 144 \frac{p_d}{\Delta\rho} = 144 \frac{66.13}{62.43 - 45.7} = 569.2\,\text{ft} \quad (1.7)$$

$$h_{\text{upper limit}} = 144 \frac{p_d}{\Delta\rho} = 144 \frac{847.9}{62.43 - 45.7} = 7298\, ft \quad (1.8)$$

*Table 6* – **Laboratory data**

| $S_{Hg}$ | $P_{Cair-Hg}$, psi | $S_{water}$ | $P_{Coil-water}$, psi |
|---|---|---|---|
| 0 | 234 | 1 | 66.13 |
| 0.158 | 281 | 0.842 | 79.42 |
| 0.375 | 324 | 0.625 | 91.57 |
| 0.533 | 379 | 0.467 | 107.1 |
| 0.731 | 576 | 0.269 | 162.8 |
| 0.838 | 1125 | 0.162 | 317.9 |
| 0.885 | 3000 | 0.115 | 947.9 |

Thus, it results that the thickness of the transition zone is:

$$7298 \text{ ft} - 569 \text{ ft} = 6729 \text{ ft} \tag{1.9}$$

## 3. CONCLUSIONS AND PROPOSALS

The following conclusions can be summarized:

– The migration of oil under the impulse of capillary forces is a phenomenon that under normal temperature and pressure conditions has a local character, a small extent that does not exceed 1.2 - 1.5 m, depending on the nature of the oil;

– the upward capillary migration speed of water is much higher than the capillary migration speed of oil, which is why the two fluids, constituting separate phases, migrate separately (oil following water);

– During upward capillary migration, the oil fractionates and the lighter fraction has a higher energy than the heavy fraction and substantially overtakes it.

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