Wettability Evaluation by Spontaneous Imbibition Measurement

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Abstract

The propensity of one fluid in a fluid pair to coat the surface voluntarily is known as wettability. Fluid distribution and flow behavior in porous rocks mainly controlled by wettability. Oil recovery by water flooding depend mainly on the wettability of the reservoir rock. Many methods used for wettability measurement. These methods are qualitative and quantitative. Spontaneous imbibition is one of widely used methods for quantitative wettability measurement. Direct measurement and weighing technique are two known methods for spontaneous imbibition measurement. This work presents comparison between the two aforementioned methods. Experimental measurement of spontaneous imbibition achieved on core samples from the same source. Results approved that the samples are water wet but having different tendencies, the imbibition rate related to time have variable trend in addition, ultimate water saturation in weighing method experiment are higher than that in volume measurement method. The weighing method is better than the volume measurement method.

Keywords: *Imbibition Test; Wettability; Weighing Method.*

1. Introduction

Wettability is defined as "a tendency of one fluid of a fluid pair to coat the surface spontaneously" by Jerald and Rathmell [1]. "The tendency of one fluid to spread or attach to solid surface in the presence of additional immiscible fluids" is Anderson's [2] second definition. Due to its close connection to oil recovery, wettability is a crucial factor in the assessment of a reservoir. It has an impact on the relative permeability, electric characteristics, fluid distribution, residual saturations, and capillary pressure [3]. Thus, the key element that enhances the oil recovery in a reservoir with poor permeability and fractures is reservoir wettability, which directly affects the recovery of oil via spontaneous imbibition [4]. It is important to research the reservoir rock's wetting characteristics.

Gas, oil, and water can all be found in porous medium. The work concentrated on oil and water solely because gas is typically a non-wetting phase [5]. Numerous variables affect wettability, including mineral composition of the rock and its chemical characteristics, temperature, pressure, salinity, pH, and multivalent cations in the brine, as well as film thickness, saturation history of the reservoir. The system is water-wet when water has a propensity to stick to the majority of the rock surface occupying the small pores, whereas the system is oil-wet when oil is in touch with the majority of the rock surface occupying the small pores. Sometimes both water and oil have a tendency to stick to the surface of the rock, creating an intermediate (or neutral) system. When distinct portions of the porous media exhibit differing wetting preferences, the term fractional wettability is often employed. It happens when the surface chemistry and mineral makeup of a rock are unpredictable [6].

2. Wettability Evaluation

Numerous methods have been used to measure the complex property of reservoir rock's wettability [7]. Both the qualitative and quantitative categories applied to these techniques. The main methods for qualitatively quantifying wettability include

visual, imbibition, relative permeability, capillary pressure, and flotation [8]. The wettability of a system is evaluated using USBM approaches, microscopic examination, Amott, Amott-Harvy, and other conventional quantitative procedures [9]. This study used the weighted technique rather than directly measuring the volume of the non-wetting period during the instantaneous imbibition test.

3. Microscopic Observation

Wetting angles on tiny rock samples must be directly observed and measured in order to do this. The equilibrium configuration of the two fluid phases when two fluids are in contact with a solid surface depends on the relative values of the surface tension between each pair of the three phases. The interface at which each surface tension acts determines the angle at which the liquid meets the surface. According to Figure 1, the value of the contact angle determines the type of wettability.

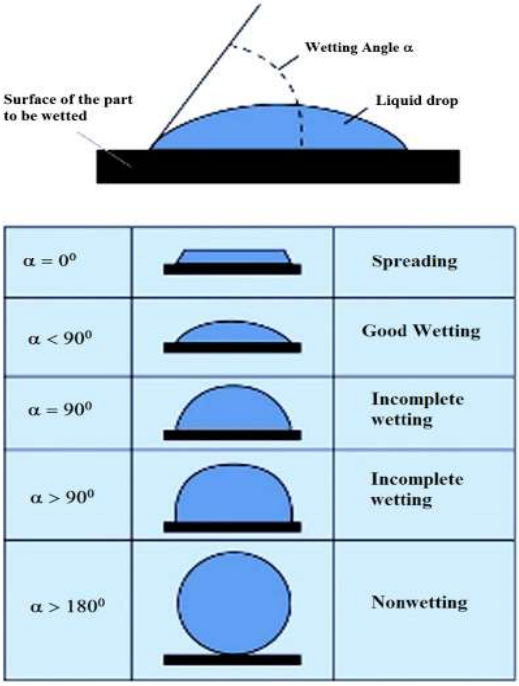

Fig 1. Wetting angle for various wetting properties [10].

The contact angle is the best wettability measurement method, but it is not used in oil industry since it is not easy to get a solid surface representing the reservoir rock composition. Obviously, the wettability of clays cannot be examined using this method [8].

4. Amott method

This approach, invented by Amott [11], uses forced displacement volumes of both oil by water and oil by oil to assess the average wettability of a core. According to Amott's test, the wettability of the rock is determined by two ratios: the displacement-by-water index, I_w, and the ratio between the amount of oil that is displaced solely by spontaneous water imbibition, V_{osp}, and the total amount that is displaced by water imbibition and centrifugal (forced) displacement, V_{ot}.

$$I_w = V_{osp} / V_{ot} \quad (1)$$

In particular, the displacement-by-oil index, I_o, compares the total volume of water displaced by oil imbibition , V_{wsp}, and centrifugal (forced) displacement to the water volume displaced solely by spontaneous oil imbibition, V_{wf}.

$$I_o = V_{wsp} / V_{wf} \quad (2)$$

These indexes reveal a rock's wetlability. I_w will be positive and Io will be zero for a strong water-wet core. Similar to this, Io will have positive values in a strong oil-wet core but I_w will be zero. Both indices are zero in the event of a neutral wet core. The "Amott-Harvey Relative Displacement Index," a variation of this technique, is becoming more popular. The steps in this modified approach are similar to those in the Amott, but before preparing the core, a further step is added that entails centrifuging the prepared core first under brine and then under crude to decrease the plug to irreducible water saturation. Consequently, the Amott-Harvey index is determined by:

$$I = Iw - Io \quad (3)$$

The wettability criteria now have a new range. A system is oil-wet when $-1 \leq I \leq -0.3$, intermediate-wet when $-0.3 \leq I \leq 0.3$, and wet under water conditions when $+0.3 \leq I \leq 1.0$.

5. USBM Method

To determine the average wettability of a rock sample, the United States Bureau of Mines (USBM) and Donaldson developed this approach [12]. The procedure is reasonably quick and takes only a few days to evaluate four to eight samples. Its sensitivity to wettability that is close to neutral is one of its key advantages over the Amott method. The work required to move one fluid over another in a porous media is compared using the USBM method. The work needed by the wetting fluid to displace the non-wetting fluid is less than the work needed for the opposite displacement because of the favorable shift in free energy. Calculating the area under the forced displacement's capillary pressure curve is necessary. Centrifuging is typically employed to displace the capillary pressure, however there are various capillary displacement methods available.

By comparing the log of the area (A_1) under the oil-displacing brine curve with the log of the area (A_2) under the oil-displacing brine curve, it is possible to calculate the sample's wettability (W). The equation that defines the USBM index is as follows:

$$W = log(\frac{A_1}{A_2}) \quad (4)$$

One test can incorporate both the Amott and USBM techniques. Figure 2 displays this combination as well as the capillary pressure map utilized in the USBM computation.

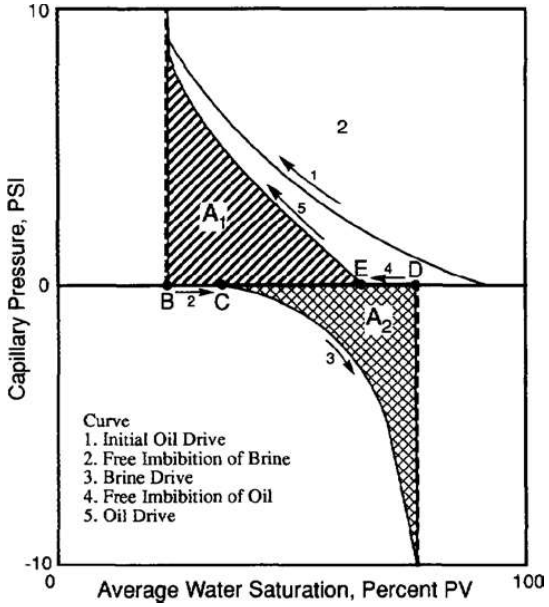

Fig 2. Relationship of wettability measurement by Amott test to Pc curves for a mixed wettability system [7].

6. Displaced Volume Measurement

Ammot, USBM and instantaneous imbibition methods measure the volume of the non-wetting phase naturally displaced from the core sample by the wetting phase (oil in a water-oil rock system) by using a glassware shown in figure 3.

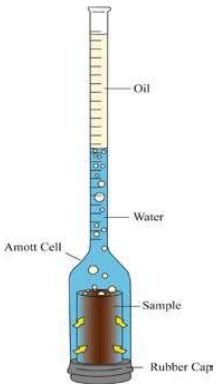

Fig 3. Measurement of the oil volume [13].

The oil saturated core sample placed into the glass chamber and covered with water. When water displacing oil, oil rises up into the graduated tube due to the difference in the specific gravity of water and oil.

Oil rises in the graduated glass column then its collected volume measured with time. Droplets of the displaced oil adhere to the surface of the core sample or adhere on the glass and did not rise into the graduated glass tube resulting in errors in the measured displaced oil volume.

7. Methodology

Five cylindrical core samples of a high porosity strong water-wet rock samples were prepared. These samples were from the same source having a volume range of 15.8-22.1 cc. These samples were cleaned, dried and weighted to calculate their pore volume and porosity. They were saturated with gas oil having density of 0.8386 gm/cc. The spontaneous imbibition tests done by two methods as follows:-

A - Weighing method

To measure the weight of the gasoil saturated samples during the imbibition test, a balancing system consist of a high precession electrical balance and metallic wire for hanging the core samples and transmitting the weight was prepared, as shown in figure 4.

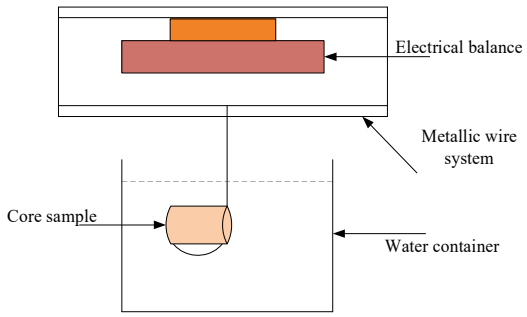

Fig 4. The balance system for the weighing method.

The tests were performed by hanging the gasoil saturated core sample by the metallic wire and completely immersed into the water container (the sample must not touch the wall or the bottom of the container) then its weight was recorded as the weight at zero-time, *Wto*. While leaving the sample completely immersed into water. Imbibition of water as a wetting phase started. Sample weight recorded (*Wt*) with time. The test and weight measurements continued until there was no appreciable change in the weight readings between two successive steps.

Water saturation at each time step calculated as follows:-

When water of 1 gm/cc density imbibed into the rock samples it displaces gas oil having a density of 0.8386 gm/cc, so there will be an increase in the weight of the suspended sample. This increase converted to water volume using the following equation:

$$V_w = \frac{W_t - W_{t0}}{\rho_w - \rho_n} \qquad (5)$$

Where V_w is the volume of the wetting phase imbibed into the porous media at any time, ρ_w and ρ_n are the density of the wetting phase (water) and the non-wetting phase(gas oil) respectively. The wetting phase saturation is calculated by dividing Vw by the pore volume of the core sample under study. For the case of oil is the wetting phase the weight of the suspended core sample will decrease with time since oil having a lower density displaces water of the higher density and eq.5 could also be used to calculate the volume of oil imbibed into the porous media.

B - Volume measurement

After finishing the former tests, the five cylindrical core samples were, cleaned, dried and re-saturated with the gasoil. The spontaneous imbibition test carried out for each of the five cores using a glassware similar to that shown in figure 3. The displaced gas oil volume collected on the glass column recorded with time and hence core water saturation could be calculated. The test finished when no appreciable increase in the collected gas oil volume.

8. Results and Discussion

For every core sample, the calculated water saturation at every time step resulted from the both adopted methods presented in figure 5.

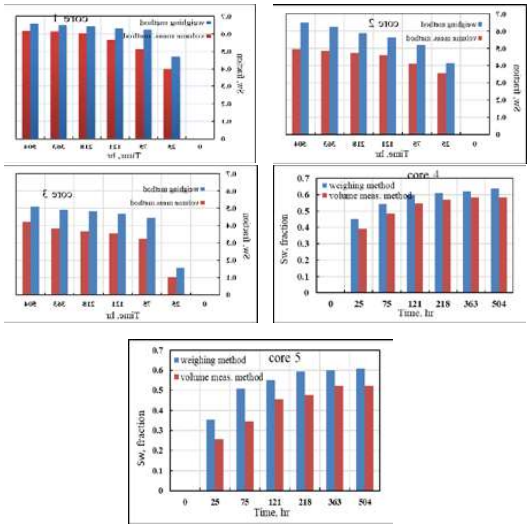

Fig 5. Readings of water saturation at different time steps.

Fig.5 shows that there is a rapid increase of the wetting phase saturation (water) with time at early time of the tests since the larger pores were occupied initially; later a slower increase of saturation is noticed since the smaller pores were occupied. In addition, it is clear that water saturation reading with time resulted from the weighing method are higher than that from the volume measurement method. This difference attributed to the adhering of the displaced gas oil droplets on the body of the core or on the glassware in the volume measurement method; hence the recorded gas oil volume will be less than the actual. While the adhered droplets could be removed out of the core body in the weighing method. This also effect on the maximum water saturation recorded for the five core samples in both tests as given in table 1.

Table 1. The maximum water saturation,

Core No.	Maximum water saturation, fraction	
	Weighing method	Volume meas. method
1	0.66	0.615
2	0.6505	0.495
3	0.51	0.423
4	0.638	0.583
5	0.607	0.522

The averaged water saturation readings for the five core samples at every time step plotted in figure 6.

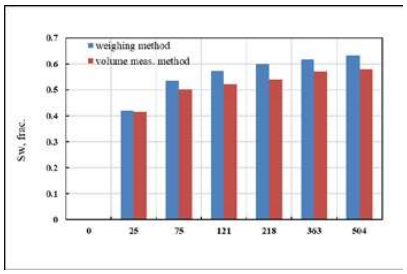

Fig 6. Averaged water saturation for the five cores.

The imbibition rate between every two successive time steps during the imbibition tests for each core sample was calculated and plotted versus time in figure 7, which clarify a variable imbibition rates during every test. This difference attributed to the dissimilarity of the pore structure of every individual core.

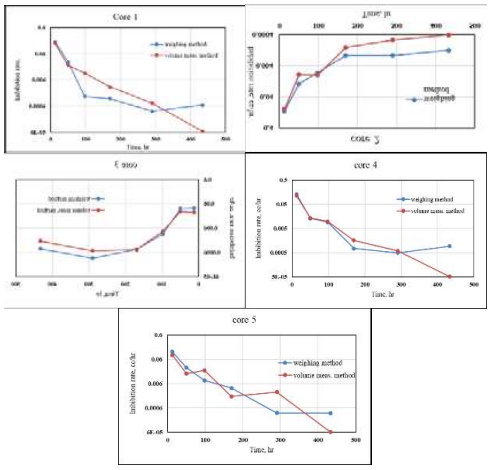

Fig 7. Imbibition rate vs time for the core samples.

9. Conclusions

All the core tested core samples are water wet as indicated by the both tests, but there is a contrast in their wettability tendency as shown in figure 5 and table 1, therefore it is necessary perform more than wettability test to get the right wettability evaluation.

The weighing technique excluded the error in reading the volume of the displaced oil which resulting from adhering of the oil droplets on

the glass surface and on the outer surface of the core sample which cause the difference between the average values plotted in figure 5. The size of the core sample used in the volume measurement method is limited to the volume of the glass chamber while any size or shape of rock sample could be used in weighing method technique.

Readings for many core samples successively at certain time in the weighing method, while in the volume measurement method the glassware used for one core sample, which make it a time consuming.

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