AGH DRILLING, OIL, GAS • Vol. 33 • No. 1 • 2016

http://dx.doi.org/10.7494/drill.2016.33.1.167

Robert Czarnota*, Damian Janiga*, Jerzy Stopa*, Paweł Wojnarowski*

LABORATORY MEASUREMENT OF WETTABILITY FOR CIĘŻKOWICE SANDSTONE**

1. INTRODUCTION

Wettability is a key factor that affects the petrophysical properties of reservoir rocks. The knowledge of reservoir wettability plays a crucial role because it impacts on different basic reservoir properties such as the distribution of gas, oil and water within reservoir rock, relative permeability and finally the potential production of hydrocarbons. Therefore, a proper understanding of the wettability of a reservoir is essential for selecting the most efficient way of crude oil recovery from petroleum reservoirs and oil field management. There are several methods of wettability evaluation. Two different groups of wettability determination method exist, these are: qualitative and quantitative measurements reported in the literature [3]. Qualitative methods include microscopic visualization of fluids distribution, relative permeability curves and imbibition methods [7]. All qualitative methods are indirectly inferred from other measurements. Quantitative methods are direct measurement methods, where the wettability is measured on actual rock samples using reservoir fluids, including oil and brine. These quantitative methods are contact angle measurement, the Amott [2] and Amot–Harvey test [5] and USBM methods [6]. The wettability effect on waterflooding was well studied. It is generally recognized that the efficiency of waterflooding in a uniformly water-wet reservoir is higher than that of uniformly oil-wet reservoir [4]. In this work the wettability has been determined by qualitative method – Amott–Harvey test. Crude oil was used and initial water saturation was established in the cores for Polish Ciężkowice sandstone, which are considered as reservoir rocks for Carpathian oil fields.

* AGH University of Science and Technology, Faculty of Drilling, Oil and Gas, Krakow, Poland

** The research leading to these results has received funding from the Polish-Norwegian Research Programme operated by the National Centre for Research and Development under the Norwegian Financial Mechanism 2009–2014 in the frame of Project Contract No. Pol-Nor/235294/99/2014

2. CORE ROCKS PROPERTIES AND PVT CHARACTERISTIC OF LIQUIDS

The experimental program was performed on two sandstone sample rocks from different formation of Carpathian sandstones. Rock material was collected from outcrops and transferred to workshop for drilling and saw cutting. As result, cylindrical shape of rocks was obtained. The core identifications are given in Table 1. Porosity and absolute permeability were performed in accordance with API-40 Recommended practices for core analysis. Porosity was measured with liquid saturation method and permeability was measured taking into account Klinkenberg gas slippage factor. The chemical and physical properties of crude oil and distilled water are shown in Table 2. Density of liquids was determined directly by measurement of mass and volume. Viscosity of crude oil was measured by means of Engler viscometer. Stalagmometric method was applied for determination of water-oil interfacial tension. Formation water was replaced with distilled water, due to lack of information about its characteristic.

Table 1

Petrophysical characteristics of core samples

Rock sample	Diameter [cm]	Length [cm]	Effective porosity [%]	Klinkenberg permeability [md]	Rock density [kg/m^3]
C25	3.75	8.58	13.22	30.72	2004
C13	3.75	7.74	11.51	11.22	2296

Table 2

Chemical and physical properties of crude oil and water used in experiments

Crude oil	Density [kg/m^3]	Viscosity [cP]	Interfacial tension for water-oil [N/m]	Water content [%]
Grobla	827	3.24 (45°C)	$29.8 \cdot 10^{-3}$	0.18
Water	1000	1		–

3. QUANTITATIVE AMOTT-HARVEY EXPERIMENT

After initial preparation and evaluation of petrophysical parameters, the quantitative method (Amott–Harvey) was used for evaluation the wettability of core plugs.

The measurements were carried out at reservoir temperature: 45°C, which is characteristic for shallow Carpathian oil fields. The following steps were used to carry out the research:

– Procedure began with complete water saturation of rock sample.
– Forced oil flooding was applied to achieve irreducible water saturation.
– Rock sample was subjected to the spontaneous displacement of oil.
– Forced displacement of oil by water.
– Immersion of the core sample in crude oil to observe the spontaneous displacement of water by oil.
– Forced displacement of water by oil.

The volume of water and oil released in the spontaneous and forced displacement steps were recorded. The spontaneous displacement for both oil and water took 21 days. Consequently, Amott–Harvey index was calculated. Index varies from –1 for complete oil wetness, +1 for complete water wetness, range from +0.1 to +0.3 is considered as slightly water wet and for –0.1 to –0.3 as slightly oil wet. Neutral wettability is acknowledged for scope from –0.1 to +0.1 Basing on Cuiec's Wettability Classification Wettability of Ciężkowice sandstone was determined.

4. EXPERIMENTAL FACILITY FOR FORCED DISPLACEMENT OF LIQUIDS

The experimental facility is shown in Figure 1 and constitutes a Hassler type core holder, four Teledyne Isco syringe pumps for controlling confining, pore and backpressures during wettability investigation. Two transfer cylinders (moveable piston type) made of highly corrosion resistant metal alloy (Hastelloy C-276) were connected to the pumps for storing and flowing the test fluids (oil and water). Two absolute and three differential pressure transducers were installed for core sample inlet, outlet and differential pressure measurement. The core holder system contains axial inlet and outlet fluid lines with corresponding pressure ports, and line for confining liquid entry and its pressure measurement. Distilled water was used for overburden pressure (5 MPa). The experiment was conducted at corresponding reservoir temperature (45°C). The outlet fluid flow line was connected to an acoustic separator and through it to a backpressure regulator (BPR).

Acoustic separator is a device equipped with an ultrasonic transducer for interface detection of two different immiscible phases (liquid/liquid, gas/liquid). In the first bore separation of collected fluids occurs, but measurement takes place in the second bore. The boundary between fluids is determined by the comparison of the travel time of the reflected pulse from the fluid interface and from a known point.

The Ciężkowice sandstone core sample was placed in rubber sleeve and then installed in core holder. Once a core sample was tightly placed between the fixed and movable end pieces of the core holder, the overburden pressure was applied in the annular space between walls of the core holder and rubber sleeve. Water and oil flooding was carried out at the mentioned confining pressure at a flow rate of 1 cc/min. Backpressure value was set at a constant level equal 1 MPa. Oil flooding was continued until no more water was displaced from the core sample and vice versa. The same procedure was followed for both rock samples.

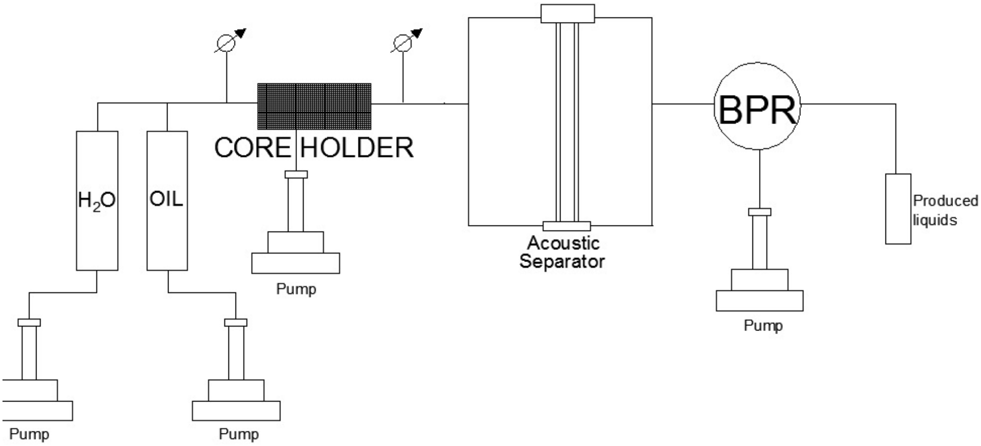

Fig. 1. Diagram of the coreflooding system

5. DETERMINATION OF WETTABILITY INDEX

Amott–Harvey wettability index is determined as follows: let V_{ws} be the volume of water spontaneously displaced by oil, V_{wf} the volume of water released by forced displacement of water by oil, $V_{wt} = V_{ws} + V_{wf}$ the volume of water from spontaneous and forced displacement, V_{os} the volume of oil spontaneously displaced by water, V_{of} the volume of oil released by forced displacement of oil by water, and $V_{ot} = V_{os} + V_{of}$ the volume of oil from spontaneous and forced displacements. Based on these steps, the test results are expressed as displacement by oil ratio – δ_o and displacement by water ratio δ_w respectively, defined by the following equations:

$$\delta_o = \frac{V_{ws}}{V_{wt}} \tag{1}$$

$$\delta_w = \frac{V_{os}}{V_{ot}} \tag{2}$$

The ratios of spontaneous displacement volumes to the total displacement volumes are used as wettability indices. These ratios allow to calculate, the Amott–Harvey wettability index:

$$I_{AH} = \delta_w - \delta_o \tag{3}$$

In Table 3 entry data, calculations and Amott–Harvey wettability values are presented. In Table 4 results of recovery factor during imbibition processes for both investigated rock samples are included.

Table 3

Data for calculation wettability index

Rock sample	V_{ws} [ml]	V_{wf} [ml]	V_{wt} [ml]	δ_o [–]	V_{os} [ml]	V_{of} [ml]	V_{ot} [ml]	δ_w [–]	I_{AH} [–]
C25	0.0	1.3	1.3	0.00	0.8	1.1	1.9	0.42	0.42
C13	0.1	1.1	1.2	0.08	0.7	0.8	1.5	0.47	0.39

Table 4

Recovery factor outcomes

Rock sample	S_{wi} [%]	V_{os} [ml]	V_{of} [ml]	V_{ot} [ml]	S_{or} [%]	RF [%]
C25	20.6	0.8	1.1	1.9	64.2	19.1
C13	19.8	0.7	0.8	1.5	64.9	19.0

6. CONCLUSIONS

Both Ciężkowice sandstone core samples in Amott–Harvey test have water wettability. In the future is recommended to perform wettability index determination with other methods and compare values.

For the proper oil field development it is suggested to carry out research on core rocks just after drilling the production wells, including application of sample preservation techniques. Moreover, important issue is that type of research is time-consuming.

More accurate evaluation of wettability in the oil fields demands to test more rock samples to provide more detailed description of wettability across a reservoir.

IOR/EOR methods are suggested for increasing oil recovery factor for Carpathian oil fields, but selecting the right technique demands further researches including routine core analysis, special core analysis, more detailed PVT description of reservoir fluids and executing advanced numerical reservoir simulations.

Results can be dependent on duration of the spontaneous displacement.

REFERENCES

[1] API: *Recommended practices for core analysis*. 2nd ed. 1998.

[2] Amott E.: *Observations relating to the wettability of porous rock*. Trans, AIME, 216, 1959, pp. 156–162.

[3] Anderson W.G.: *Wettability literature survey. Part 2: Wettability measurement*. JPT, Paper No. 13933, vol. 38, No. 11, 1986, pp. 1246–1262.

[4] Anderson W.G.: *Wettability literature survey. Part 6: The effects of wettability on waterflooding*. J Petrol Technol, 39(12) 1, 1987, pp. 605–601, 622.

[5] Boneau D., Clampitt R.: *A surfactant system for the oil-wet sandstone of the North Burbank Unit* SPE-5820-PA, 1977.

[6] Donaldson E.C., Thomas R.D., Lorenz P.B.: *Wettability determination and its effect on recovery efficiency*. SPE Journal, Paper No. 2338, vol. 9, No. 1, 1969, pp. 13–20.

[7] Esfahani M.R., Kazemzadeh E.A., Hashemi S.M., Karimaie H.: *Determination of wettability of Iranian carbonate reservoir rocks in restored-state*. JUST, 33(1), 2007, pp. 1–9.

[8] Jadhunandan P.P., Morrow N.R.: *Effect of wettability on waterflood recovery for crude oil/brine/rock systems*. SPE Reservoir Engineering, Paper No. 22597, vol. 10, No. 1, 1995, pp. 40–46.

[9] Poston S.W., Ysrael S., Hossain A.K.M.S., Montgomery III E.F., Ramey Jr. H.J.: *The effect of temperature on irreducible water saturation and relative permeability of unconsolidated sands*. SPE Journal, Paper No. 1897, vol. 10, No. 2, 1970, pp. 171–180.

[10] Torsaeter O.: *A comparative study of wettability test methods based on experimental results from North Sea reservoir rocks*. SPE Annual Technical Conference and Exhibition, Paper No. 18281, Houston, Texas, 2–5 Oct. 1988.

[11] Treiber L.E., Archer D.L., Owens W.W.: *A laboratory evaluation of the wettability of fifty oil producing reservoirs*. SPE Journal, Paper No. 3526, vol. 12, No. 6, 1972, pp. 531–540.