Journal of Petroleum Science and Engineering 142 (2016) 77–84

Contents lists available at ScienceDirect

Journal of Petroleum Science and Engineering

journal homepage: www.elsevier.com/locate/petrol

Experimental investigation of effect of temperature and pressure on contact angle of four Iranian carbonate oil reservoirs

Adel Najafi-Marghmaleki, Ali Barati-Harooni*, Aboozar Soleymanzadeh, Seyed Jamal Samadi, Babak Roshani, Amir Yari

Department of Petroleum Engineering, Ahwaz Faculty of Petroleum Engineering, Petroleum University of Technology, Ahwaz, Iran

ARTICLE INFO

Article history:
Received 23 November 2014
Received in revised form
2 February 2016
Accepted 3 February 2016
Available online 4 February 2016

Keywords:
Wettability
Contact angle measurement
Captive drop instrument
Live oil
Carbonate reservoir

ABSTRACT

The knowledge of reservoir wettability is essential to understand the fluid displacement mechanisms, and to develop strategies for achieving higher recovery factors. Wettability is an important parameter which controls the remaining oil in place. It has a significant effect on multiphase rock fluid interactions. The objective of the present work is to investigate the influence of temperature and pressure on the wettability of four Iranian carbonate oil reservoirs. The contact angles were measured between live oil, synthetic formation water and slices of rock which were cut from different depths of reservoirs. The contact angles were measured by using captive drop system. The pendant drop method was used to measure the interfacial tension between live oil and synthetic formation water. In order to measure contact angle and interfacial tension, sixteen runs were undertaken for each of these four reservoirs at pressures 3000, 3500, 4000, and 4500 psi which all were above the bubble point pressure of these reservoirs and four temperatures which were the ambient temperature, reservoirs crest temperature, the temperature of water oil contact (WOC) and a temperature between the temperature of crest and WOC. Results demonstrated that pressure alone had little effect on the wettability of reservoir rock. Increase in temperature mostly changed the wettability of reservoir rock from water wet to intermediate wet system. The effect of temperature on each system differs from others and in some cases the contact angle decreased with increasing temperature but the general trend was increasing. The results of SARA-test showed that the ratio of resin to asphaltene in reservoir D was higher than reservoir A, hence it is expected that the contact angle of reservoir D to be lower than reservoir A which was shown in our results. In addition experimental data were analyzed by an equation of state model and it was observed that this model could predict the experimental contact angles with an acceptable accuracy.

1. Introduction

Wettability is spreading of a fluid on solid surface in the presence of another immiscible fluid. Tiab and Donaldson (2012) described the wettability by noting that it is the comparative adhesion of two fluids on a solid surface. Knowledge of wettability is important for the estimation of oil reserves and for the prediction of production performance. It affects the distribution of water, oil, and gas within a reservoir rock, which in turn affects the displacement behavior and relative permeability characteristics. Wettability is also important to the success of enhanced oil recovery operations.

Previous studies about the effects of temperature and pressure on contact angle indicate that observed trends depends on the condition of system which is under study. Jones and Adamson (1968) studied the temperature dependence of contact angle for naphthalene–water–air system. They found that contact angle decreases with temperature. Poston et al. (1970) conducted measurements on contact angle (oil–water–glass) as a function of temperature ranged from room temperature to 190°F at atmospheric pressure by sessile-drop ratio method and reported decreasing trend with temperature. Wang and Gupta (1995) studied the effect of temperature and pressure on wettability. They used modified pendant drop method. Their experiments were conducted on mineral oil–distilled water and two crude oil-brine systems. Crude oil (a) was from a carbonate reservoir and crude oil (b) was from a sandstone reservoir. Therefore, a calcite crystal was used with crude oil (a) and a quartz crystal was used with crude oil (b). The experiments were conducted at pressures ranged from 200 to 3000 psig. The temperature was ranged from room temperature to 200 °F. They concluded that contact angles were not very sensitive to pressure but the temperature had notable impact

* Corresponding author.
E-mail address: alibarati.2012@yahoo.com (A. Barati-Harooni).

http://dx.doi.org/10.1016/j.petrol.2016.02.004
0920-4105/

on contact angles. The contact angles were increased by increase in temperature for Quartz crystals and decreased by increase in temperature for calcite crystals. Hjelmeland and Larrondo (1983) studied the effect of pressure and temperature on contact angle for both stock tank oil and live oil but they used calcium carbonate crystals. Their results showed that temperature had substantial effect on wetting characteristics of calcium carbonate crystals and no effect of pressure was found on wettability. Okasha and Al-Shiwaish (2010) presented the effect of temperature and pressure on contact angle of Khuff gas reservoir. The pressure was increased from 500 psig to 3000 psig and the temperature was raised from room temperature to 90 °C. They observed a general trend of decrease in contact angle values with an increase in temperature at maximum testing pressure (3000 psi). Preparation of a smooth solid surface like calcium carbonate crystals is recognized to be an important factor in obtaining reproducible results. However, the surface of porous medium which hydrocarbons are present is not totally smooth. Mixed mineral composition, the heterogeneity and roughness of solid surface and the geometry of pores can all be expected to influence reservoir wetting properties. Because of these heterogeneities it is important to use real reservoir rock in order to deal with the wettability of oil reservoirs. Anderson (1986b) in his wettability review noted that contact angle on smooth surfaces remains fixed and does not change, whereas on rough surfaces, as in reservoir rocks, where the surface exhibit non smooth behavior, depends on the geometry of the rock surface. So it is very important to use real reservoir rocks instead of crystals to determine reservoir wetting characteristics. Only a few investigations that deal with wettability of real reservoir fluids and rocks at reservoir pressure and temperature have been reported in the literature. Because we knew that temperature and pressure might play an important role in wettability, this study was undertaken to evaluate the effect of these factors on the interfacial properties of four Iranian carbonate oil reservoirs named A, B, C and D. Experiments were carried out with synthetic formation water and live oil. Carbonate cores of these four oil reservoirs were used to represent pore walls of reservoirs. The contact-angle (captive drop instrument) method was used to quantify wettability.

2. Materials

2.1. Fluids

All experiments were carried out using crude oil and synthetic formation water which were taken from four Iranian carbonate oil reservoirs. Gas and oil samples were taken from first-stage separators. Stock tank oil was filtered through a Whatman filter paper no. 41 before recombination. Live oils were prepared by recombining the gas and oil according to the gas–oil ratio (GOR) of the reservoirs. Synthetic formation water samples were prepared based on geochemical analysis of the produced water from the A, B, C and D oil reservoirs. The salinity of synthetic formation water samples and bubble point pressure of each reservoir are listed in Table 1. The densities of reservoir oil and synthetic formation water determined with DMA-HP densitometer of Anton Paar Company with evaluation unit of (DMA-5000) are shown in Tables 2 and 3. These values were used in interfacial tension measurements. The results of SARA-test for reservoir A and reservoir B are shown in Table 4.

Table 1
Salinity of synthetic formation water and bubble point pressure of each reservoir.

Reservoir	Salinity (ppm)	Bubble point pressure (psi)
A	180,000	2225
B	180,000	2116
C	186,000	2026
D	190,000	2039

Table 2
Density of live oil at different temperature and pressure for different reservoirs.

Reservoir	Temperature (°C)	Pressure (psi)			
		3000	3500	4000	4500
A	25	0. 814046	0.81467	0.815705	0.817183
	60	0.798515	0.799438	0.800777	0.802553
	80	0.790388	0.790511	0.791325	0.792641
	91	0.777414	0.778258	0.77995	0.781634
B	25	0.832227	0.834734	0.837192	0.839813
	60	0.810505	0.812619	0.815001	0.817448
	101	0.792327	0.794007	0.7962	0.79878
	110	0.772093	0.774124	0.777073	0.779835
C	25	0.807199	0.809651	0.812184	0.814724
	55	0.796865	0.799236	0.801355	0.803699
	81	0.775739	0.778205	0.780832	0.783507
	100	0.756241	0.758784	0.761476	0.764308
D	25	0.838905	0.841038	0.843406	0.845687
	43	0.828571	0.830624	0.832577	0.834662
	70	0.803868	0.805708	0.807719	0.810037
	100	0.799728	0.801636	0.803743	0.806244

Table 3
Density of synthetic formation water at different temperature and pressure for different reservoirs.

Reservoir	Temperature (°C)	Pressure (psi)			
		3000	3500	4000	4500
A	25	1.124815	1.129778	1.132834	1.1358
	60	1.094236	1.095965	1.097708	1.099582
	80	1.079559	1.081375	1.083206	1.084784
	91	1.073994	1.075747	1.077551	1.079286
B	25	1.124815	1.129778	1.132834	1.1358
	60	1.094236	1.095965	1.097708	1.099582
	101	1.072645	1.074442	1.076302	1.078123
	110	1.063108	1.065055	1.066825	1.068737
C	25	1.128631	1.130599	1.132307	1.133816
	55	1.109392	1.111328	1.113006	1.11449
	81	1.092386	1.094292	1.095945	1.097405
	100	1.080104	1.081988	1.083623	1.085066
D	25	1.126727	1.128693	1.130398	1.131904
	43	1.105927	1.107856	1.109529	1.111008
	70	1.08551	1.087403	1.089046	1.090497
	100	1.078283	1.080163	1.081795	1.083237

Table 4
SARA test for A and D reservoirs.

Reservoir	Saturated %	Asphaltene %	Resine %	Aromatic %
A	30.49	8.41	8.93	52.17
D	22.09	5.18	18.32	54.41

2.2. Slice of reservoir rock sample

The slice of carbonate rock samples were obtained from four Iranian oil reservoirs. These samples are labeled A_1, B_1, C_1 and D_1. First, rock samples were cleaned using toluene through soxhlet extraction apparatus. Then the samples were cleaned further with methanol through soxhlet extraction at similar condition and duration. The samples were heated in the oven at 90 °C for 24 h. The rock samples were aged with the oil at reservoirs temperature for 4 weeks. The depths of rock samples are listed in Table 5.