The study on changes in the rock wettability during the experiment

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Abstract

The reservoir wettability can change or reverse in the process of water flooding and under the action of external treatment, it will produce great influence to the oil and water flow event, even affect oil ultimate recovery factor. This paper takes the prisoner experimental basis drop method to carry on the wettability, core wettability changes and differences was studied both high and low permeability in the process of oil displacement experiment. The results show that the low permeability core is given priority to with water; The method of wash oil used often in oil displacement experiments seriously changed the wettability of core, make it more be oil-wet. By a certain time of water to wash, it can basically eliminated the effect, making the core wettability recovery to the initial state basically. Therefore, the research on the wettability of core should be done before wash oil or after water to wash.

Keywords

Wettability, contact angle, displacement experiment.

1. Introduction

Reservoir wettability is a basic feature of reservoir property parameters, which have influence to oil and water relative permeability, the distribution of remaining oil in the reservoir and water injection development characteristics [1]. In low permeability fractured reservoir water flooding development process, water displacement recovery depends on the water ability of spontaneous infiltration and absorption into base rock and oil displacement to crack [2]. In strong water wet reservoirs, strong capillary force cause very high infiltration absorption displacement efficiency; and in mixed wetting or oil wet reservoirs, the very weak capillary tube results in infiltration absorption process reduced or disappeared, seriously affect the water drive recovery factor[2-3]. Currently, low permeability oil and gas fields account for 10% of the continental petroleum geological reserves, the low permeability reserves is more than half of proven undeveloped reserves[4]. Wettability is one of the main factors affecting the low permeability and fractured reservoir permeability oil displacement, therefore, studying the technology of changing reservoir wettability to improve oil recovery has a certain guiding significance to improve the water flooding and enhance oil recovery [5].

Distribution in pores of fluid is closely related to the wettability of rock . First of all, the contact angle of the experiment core is measured by Optical Contact Angle Measuring Device for studying the influence of wettability on the distribution of fluid .

2. Experimental Program

In order to compare and analyze the difference between low permeability cores and high permeability cores, the experiment was carried out at the same time by selecting 5 middle-high permeability cores. The hearts of 10 pieces of rock has 8 blocks from the Daqing Oil Field Co. the 6st Oil Production

Plant in Gaotaizi oil layers, which belongs to third class oil layer; 2 blocks from the Daqing Oilfield Co. the 1st Oil Production Plant of grape flower oil layers (see Table 1 for the number of cores), which belongs to first class oil layer.

Core data are shown in Table 1.

Table 1. Data of cores

Core number	Permeability/10-3μm2	Position
P1	1476.96	Putaohua
G1	1470.50	Gaitaizi
G1	525.68	Putaohua
G2	520.36	Gaitaizi
G3	111.20	Gaitaizi
G4	34.91	Gaitaizi
G5	13.01	Gaitaizi
G6	8.59	Gaitaizi
G7	0.13	Gaitaizi
G8	0.06	Gaitaizi

3. Experimental conditions and experimental characteristics

(1)Experimental conditions

The experimental materials used in this experiment are the distilled water and natural cores of table 1. The equipment used in the experiment is Optical Contact Angle Measuring Device produced by German Dataphysics company (Optical Contact Angle Measuring Device, OCA). Surface / interfacial tension measurement range is 1×10-2～2×103mN/m; optical system: High quality continuous focus six magnification zoom lens (0.7 ~ 4.5 times magnification), 752 x 582 pixel CCD camera .

(2) Experimental characteristics

1) Measuring dynamic and static contact angle by sessile drop method;

2) Analysis droplet shape by pendant-drop method.

3) Analysis wetting behavior on solid surfaces

4) Calculating free energy and its composition on solid surface

5) Analysis liquid drop shape, measuring surface / interfacial tension

4. Experimental conditions

Contact Angle is formed when liquid / gas interface meet solid surface, degree as a unit, between 0 to 180 degrees . For a given system, the contact angle is specific and depends on the interaction between the three interface (liquid / gas, solid / gas and liquid / solid).

The Optical Contact Angle Measuring Device (Optical Contact Angle Measuring Device, OCA) measurement range of contact angle is 0～180°, the measurement precision is±0.1°, measurement range of surface / interfacial tension is 1′10-2～2′103 mN/m, with a resolution of ±0.05 mN/m .

5. Experiment Principle

Measurement methods can be Sessile Drop method, Pendant Drop method and Lamella configuration method. This experiment uses the Sessile Drop method. The principle that Sessile Drop method measures the surface and interfacial tension is same as Pendant Drop method. Because both methods can be described by the same Bashforth-Adams equation (The only difference is that droplet itself gravity makes the symbol before the contribution of pressure inside the droplet phase is opposite). But the method that using Sessile Drop method to measure the surface and interfacial tension of liquid

is far from common with Pendant Drop method, the main reason is former accuracy, reliability and sensitivity are all inferior to the latter. When we use Sessile Drop method to measure the surface and interfacial tension, we need select a reason that is try not to wetting the substrate surface of measuring liquid, to make the contact angle that droplet is above the substrate as possible as big, so that sessile drop we get meet to the degree which is under the premise of the central shaft rotational symmetry may be higher.

Introduce the Constrained Sessile Drop to overcome the impact of Sessile Drop method measuring in the condition of central axis rotation asymmetry, improve the accuracy and reliability and expand its range of application. This method has no change in the measuring principle, only use the supporting container that is designed and produced specially. It has perfect circular cross section and sharp edge. When add liquid to it and form a droplet, the droplet will be restricted by its figure and be forced to keep a perfect rounded contact underside, thus make the formed droplet appears good central axis rotation symmetry.

Compared with the hanging drop method, sessile drop method has the following advantages:

(1)The droplets of sessile drop method are not from the needle or capilary, which makes the operation much more convenient, not only on some substance but also on some case, cleaning after measuring are simpler.

(2) In some case, tearing and dropping down may happen in hanging drop method .When the volume increases to the surface tension can't support or when the surface tension smaller as schedule, small to can't support the weight of the hanging drop, and under the mechanical vibration.This will bring inconvenience to long time researching of the same droplet.Sessile drops method do not have these problems.

(3)Compared with the hanging drop method, sessile drop method is more suitable for high temperature and high pressure measurement.

6. Measuring result of contact angle

Three groups of experiment to measure the wettability are designed, in order to make out the extent of the wetting angle measurements' effect in displacement process, and make out these effects can be eliminated by water flowing or not, to have an accurate judgments core wettability during the flooding process simultaneously.

According to the methods of wettability division, hydrophilic core's wetting angle is less than 75 °; intermediate core's wetting angle is less than 105 °and more than 75°for oil-wet cores; lipophilic core's wetting angle is more than 105°.

The first experiment is to measure the core wettability before washing displacement; the second experiment is to measure the core wettability after oil washing; the third experiment is to measure the wettability of the natural core which is flooded by purified water in five hours, in order to rinse the toluene thoroughly throughout the core.

(1)Measurement of contact angle before washing oil

The experimental results show that five pieces of low permeability cores most hydrophilic characteristics. Three of them are water-wet core, numbered G7, G6 and G5 respectively. neutral wetting cores 1, numbered G8; oil wet core 1, numbered as G4. One neutral wetting core numbers for the G8 and one oil wet cores numbers for G4.

As seen in table 2, five pieces of high permeability cores most lipophilic characteristics. There is a water wet core, numbered G3, two neutral wetting cores, numbered G1 and P1, two oil wet cores, numbered 2 and P2.

Table 2 Initial contact angle of cores

Core number	G8	G7	G6	G5	G4
Permeability /mD	0.06	0.13	8.59	13.01	34.91
Contact angle / °	94	69	65	67	123
Core number	G3	G2	P2	G1	P1
Permeability /mD	111.20	520.36	525.68	1470.50	1476.96
Contact angle / °	34	110	108	97	94

(2)Measurement of contact angle before wash oil

From table 3 we can see that after washing oil contact angles of natural core occurred significant changes, most of the core is lipophilic, only one block core is neutral wetting, core number as G3.

It can be seen from above results, wash oil process of core wettability effect is obvious.

If the oil displacement experiment directly after the wash oil, will affect the accuracy of experimental results.

Table 3 Contact angle of cores after oil washing

Core number	G8	G7	G6	G5	G4
Permeability/mD	0.06	0.13	8.59	13.01	34.91
Contact angle/ °	132	124	125	128	127
Core number	G3	G2	P2	G1	P1
Permeability/mD	111.20	520.36	525.68	1470.50	1476.96
Contact angle / °	100	136	131	122	119

(3)Contact angle measurement after water scrubbing

Make the natural core pure water flooding 5 hours after oil washing, in order to remove residual toluene in cores, make natural core's wettability as far as possible close to the initial state. After washing measured its wettability and the results as shown in table 4.

Can be seen from table 4, after washing, most contact Angle of core have varying degrees of decline. After washing 5 piece core ,there are three piece of low permeability cores is water wet, numbering the G7, G6 and G5 respectively; Oil wet core 2 block,number of G8 and G4 respectively. 5 pieces of high permeability cores water wet in one piece, Numbers for G3; Oil wet core 2 block, number of G2 and P2 respectively .Neutral wetting 2 block, number of P1 and G1 respectively.

Table 4 Contact angle of cores after water flooding

Core number	G8	G7	G6	G5	G4
Permeability /mD	0.06	0.13	8.59	13.01	34.91
Wetting angle / °	114	66	71	73	121
Core number	G3	G2	P2	G1	P1
Permeability /mD	111.20	520.36	525.68	1470.50	1476.96
Wetting angle / °	46	124	114	102	99

Table 5 is comparison of the contact angle in the initial condition and the contact angle after water washing of the core.

Table 5 Contrast between initial contact angle and contact angle after water flooding

Core number	G8	G7	G6	G5	G4
Permeability /mD	0.06	0.13	8.59	13.01	34.91
Initial wetting angle / °	94.272	68.74	64.812	66.776	122.75
Wetting Angle after washing / °	114	66	71	73	121
Core number	G3	G2	P2	G1	P1
Permeability /mD	111.20	520.36	525.68	1470.50	1476.96
Initial wetting angle / °	34.37	109.984	108.02	97.218	94.272
Wetting Angle after washing / °	46.154	123.732	113.912	102.128	99.182

As can be seen from the table 5, five low permeability rocks in the heart, there's 4 blocks that initial wettability and wettability after washing are correspond, does not meet the one. The the initial wettability and wettability after washing of numbers on G7, G6 and G5 natural cores for water wet; numbers on G4 natural core initial wettability and wettability after washing are oil wet; number on G8 natural cores of initial wettability for neutral wetting, after washing is oil wet.

The initial wettability and wettability after washing are all in agreement of five middle-high permeability core . Initial wettability and wettability of the numbers on G3 natural core after washing for water wet; Initial wettability and wettability of the numbers on G2, P2 natural cores are oil wet; Initial wettability and wettability of the numbers on G1 and P1 of the natural core are neutral wetting.

7. Flooding experiment

The natural core of measuring wettability end were studied in water flooding experiment respectively.

The water used in saturated model is synthetic brine, the degree of mineralization is 6778mg/L ; the oil used in the experiment is simulated oil made from filtered crude oil and kerosene, which viscosity as 10mPa.s at 45℃; the experiments were carried out at 45 C, and the flooding rate of 0.2ml/min was used to carry out the water flooding to the outlet end of the natural core with water content of 98%.

Flooding experimental results of each core are shown in Table 6.

Table 6 Experiment data of flooding

Core number	G8	G7	G6	G5	G4
Permeability measured by water /md	0.06	0.13	8.59	13.01	34.91
core length /cm	3.61	8.80	8.41	4.91	4.85
core volume/cm3	17.54	42.76	40.83	23.84	23.53
PORV /cm3	3.99	9.75	8.74	5.30	5.96
porosity /%	19.94	21.00	21.61	22.47	23.55
saturated oil /ml	2.17	4.80	4.49	2.47	2.98
initial oil saturation /%	54.97	49.71	51.96	47.14	50.50
oil production /ml	0.30	0.86	1.06	0.61	0.99
waterflooding recovery /%	14.09	18.07	23.84	24.73	33.45
Core number	G3	G2	P2	G1	P1
Permeability measured by water /md	111.20	520.36	525.68	1470.50	1476.96
core length /cm	8.33	6.08	4.12	8.10	8.32
core volume /cm3	40.88	29.84	20.22	39.74	40.83
PORV /cm3	10.05	8.33	5.30	9.95	10.86
porosity /%	24.83	26.19	26.49	26.59	26.86
saturated oil /ml	5.40	5.30	3.28	6.06	6.62
initial oil saturation/%	54.31	64.28	62.52	61.52	61.54
oil production /ml	1.99	2.17	1.39	2.74	3.04
waterflooding recovery /%	37.21	41.36	42.88	45.62	46.41

It can be seen from table 6, water flooding recovery rate decreased. with the decrease of permeability. The recovery ratio of 5 low permeability cores ranged from 14% to 34%.

8. Conclusion

1. The \wettability experiment showed that, washing process can significantly change the wettability of cores. So when research the relationship between residual oil saturation and wettability, need to washing for a period of time after washing oil.

2. Low permeability cores are mainly water wettability, middle-high permeability cores are mainly intermediate wettability and oil wettability.

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