IOP Conference Series: Earth and Environmental Science

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To cite this article: Heng Song *et al* 2017 *IOP Conf. Ser.: Earth Environ. Sci.* **61** 012019

IOP Conf. Series: Earth and Environmental Science **61** (2017) 012019 doi:10.1088/1755-1315/61/1/012019

Research the migration pattern of oil-gas interface in gas cap expansion reservoir

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Abstract. Gas is continuously driven into the oil rim with the decrease of the oil rim pressure during the process of gas-cap expansion. In order to study the morphological changes in the process of oil-gas interfacial migration, the one-dimensional displacement device is used to analyze the oil-gas interface at different displacement angle and displacement velocity. The results show that the migration of outer boundary is faster than the inner boundary of the oil and gas interface in the process of oil-gas interfacial migration, and there are big differences in migration pattern of oil-gas interface at different displacement angle and displacement velocity. In order to quantitative character the interface morphology with different the displacement angle and displacement velocity, the new factor is used to describe the oil and gas interface morphology and the value of the factor can be calculated using the displacement angle and displacement velocity. The relationship between oil-gas interface form factor and displacement velocity is logarithmically determined for different displacement angles, which can provide guidance for the rational exploitation of gas-cap expansion energy with gas cap reservoir to achieve the aim of improving the overall development effect of gas cap reservoir

1. Introduction

With the development of oil and gas fields and the growing demand for natural gas and oil in the world economy, the development of gas cap reservoirs has been paid more and more attention. Gas cap and oil rim are under the same pressure system, any one of the pressure changes will cause the other side of the pressure changes, but also lead to oil-gas interface migration. In order to make full use of natural energy, the conventional development method of gas cap reservoir is to develop the gas cap after exhausting the oil rim [1-2]. During the process of gas cap expansion, the oil-gas interface is continually migration with the decrease of the oil rim pressure. Due to the influence of migration velocity and displacement angel, the oil-gas interface will change its shape, so some of oil production wells which at the border of the interface will be shut due to the gas breakthrough into the production well [3]. It is necessary to carry out the one-dimensional displacement experiment by physical simulation, and to study the law of oil and gas interfacial migration in different displacement angle and displacement velocity, which is helpful to make reasonable use of gas cap expansion energy and improve the overall development effect of gas cap reservoir [4-6].

2. One Dimensional Visualization Physical Experiment

One-dimensional visualization experimental device is used to study the migration law of the fluid interface during the process reservoir development. The device is 350mm long, the device ends for the round face and the diameter is 27mm. The two end faces each have a 3 mm diameter orifice, which may serve as an inlet end and an outlet end (Figure 1).

Figure 1. One-dimensional visualization experimental device

The device body is made of organic glass, using the glass beads as a porous medium which with a higher degree of visibility. At the same time, in order to make the experimental results easy to observation, the choice of the fluid color has a strong contrasts, the gas sample is nitrogen gas. The oil sample is kerosene which dyed with red ink. Also equipped with nitrogen cylinders, pressure gauges and gas metering device, which composed of the entire experiment system (Figure 2).

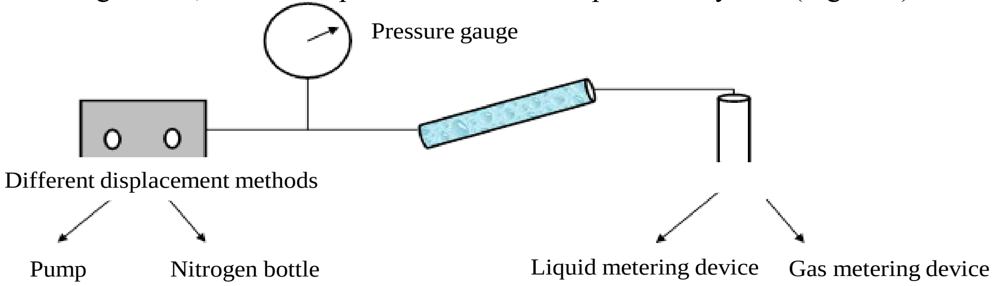

Figure 2. The experimental flow chart

3. GOC Migration Morphology

In order to study the migration pattern of oil-gas interface at different displacement velocity and dip angle, there are five sets of displacement velocity and four sets of strata dip angle. Since the displacement velocity is affected by the injected nitrogen volume, the designed displacement velocity is replaced by the gas injection rate. The injection rate is 0.01mL/min, 0.05mL/min, 0.1mL/min, 0.5mL/min, 2.5mL/min. And the corresponding actual displacement velocity is 0.0016m / d ~ 0.16m / d, the strata dip angle is 5°, 10°, 15°, 20°.

Taking the formation dip angle of 10° as an example, the oil and gas migration patterns at different gas injection rates are compared. When the gas injection rate is 2.5mL/min, gas flooding fingering serious, so the oil and gas distribution is more dispersive, there is no obvious oil-gas interface. At this displacement velocity, the recovery degree of the oil rim is only 2.8%. When the gas injection velocity is 0.5mL/min, the migration velocity of the oil-gas interface is obviously slowed down compared with the injection velocity of 2.5mL/min, the gas fingering phenomenon is suppressed and the recovery degree of the oil-rim is increased to 7.5%. When the gas injection velocity is 0.05mL / min, the oil-gas interface migration speed is slower, and the recovery degree of the oil-rim is 14.5% when the gas cap breakthrough into oil well (Figure 3, Table 1).

The two characteristics of oil-gas interface migration can be found by displacement test. One is that there is a big difference in vertical migration distance between the outer boundary and inner boundary of oil and gas interface. And the migration distance of the outer boundary is greater than the inner boundary of the oil-gas interface. Also when the oil rim recovery is similar, it is obvious from the displacement test that the difference in the vertical migration distance is greater when the injection rate increased.

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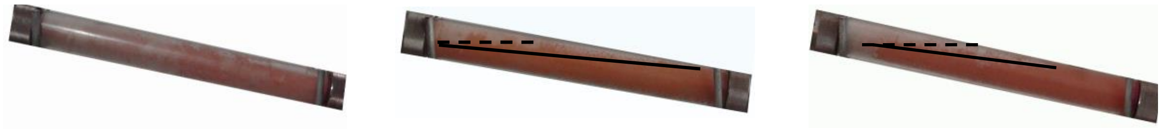

Displacement velocity 2.5mL/min, oil recovery 10.3% | Displacement velocity 0.5mL/min, oil recovery 7.5% | Displacement velocity 0.05mL/min, oil recovery 8.4%

Figure 3. oil-gas interfacial at different displacement velocity

Table 1. The recovery degree of oil rim at different displacement velocity

Displacement velocity (mL/min)	0.05	0.5	2.5
Oil rim recovery (%)	14.5	7.5	2.3

4. Quantitative Characterization of oil - gas Interface Morphology

In order to quantitatively characterize the variation of interface morphology with different displacement velocity and different dip angles, the new factor can be defined as the ratio of the outer boundary migration distance to inner boundary migration distance (Equation 1, Figure 4).

$$\delta = \frac{y1}{y2} \tag{1}$$

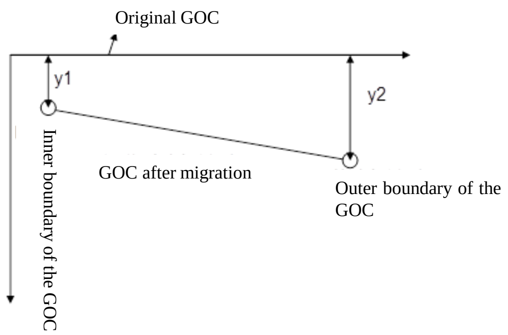

Figure 4. The illustration of the oil -gas interface morphology factor

When the strata dip angel is 10°, According to the definition of oil and gas interfacial morphology factors, the factor at different displacement velocity in the one-dimensional displacement experiment is calculated and plotted into the plane rectangular coordinate system (Figure 5). The displacement velocity in the figure has been converted to the actual transport velocity.

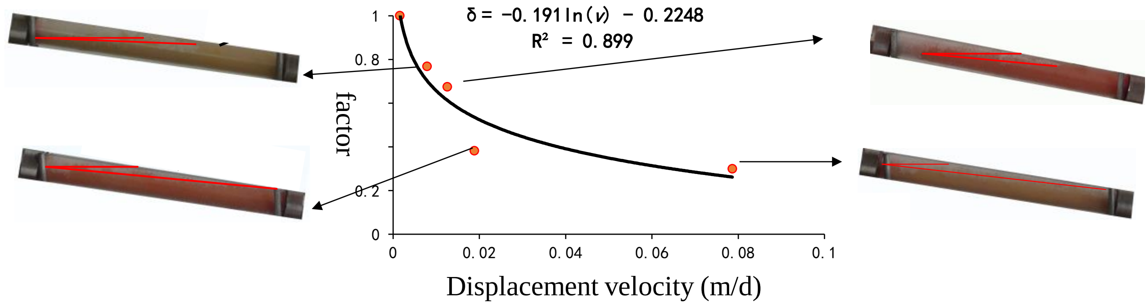

Figure 5. Morphological factors of different displacement velocity (strata dip angle 10°)

From the relationship curve, it can be seen that with the increase of displacement velocity, the interfacial morphology factor decreases, which indicates that the difference of the outer boundary migration distance and inner boundary migration distance is bigger, and the oil-gas interface is more unstable. When the dip angle of formation is 10°, the mathematical equation can be acquired

(Equation 2).

$$\delta = -0.191\ln(v)\,0.2248 \tag{2}$$

Where, δ is the interface morphology factor; v is the displacement velocity;

On the basis of pre-research, the interface morphology factor can be calculated with different gas injection rate and displacement angel. The gas injection rate includes 0.01 mL/min, 0.05 mL/min, 0.1 mL/min, 0.5 mL/ min, 2.5 mL/ min. The angle of includes 5°, 15°, 20° (Figure 6).

It can be seen that when the displacement velocity is the same, the larger the dip angle is, the larger the factor is, the greater the dip angle is, and oil and gas interface is more stable, and the difference between the velocity of GOC outer boundary and GOC inner boundary is getting smaller. When the dip angle is the same, with the increase of the displacement velocity, the oil and gas interface morphology factor decreases, which indicate that the difference of the velocity of GOC outer boundary and inner boundary is larger and the oil and gas interface becomes more unstable.

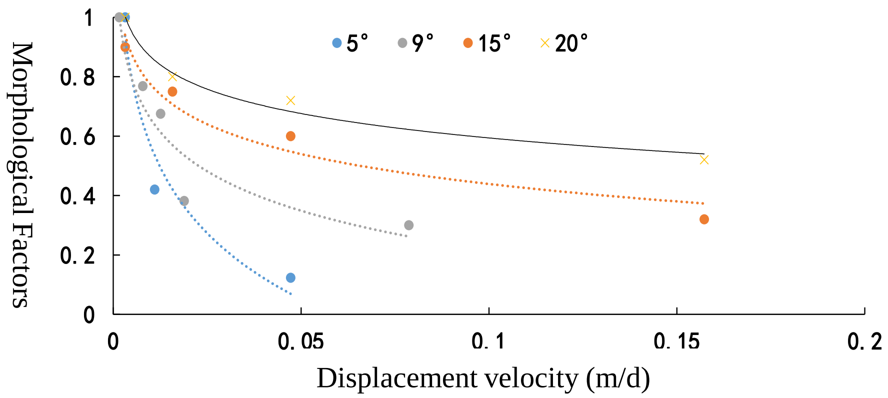

Figure 6. The relationship between morphological factors and displacement velocity in different strata dip angle

In the same way, the relationship between oil-gas interface morphological factors and displacement velocity can be obtained by fitting in different strata dip angle including 5°, 15°, 20°.

When the dip angle is 5°, the equation is:

$$\delta = -0.321\ln(v) - 0.9092 \tag{3}$$

When the dip angle is 15°, the equation is:

$$\delta = -0.1451\ln(v) + 0.105 \tag{4}$$

When the dip angle is 20°, the equation is:

$$\delta = -0.118\ln(v) + 0.3212 \tag{5}$$

Based on the above equations, it can be seen that the relationship between oil-gas interface morphological factors and displacement velocity is in logarithm. It can be expressed by the following equation.

$$\delta = a\ln(v) + b \tag{6}$$

The coefficients a and b of the equation can be regressed, and the relationship between the coefficient and the dip angle is obtained (Figure 7, Equation 7 and Equation 8).

$$a = -0.0116\alpha^2 + 0.3337\alpha - 2.2873 \tag{7}$$

$$b = -0.0025\alpha^2 + 0.0673\alpha - 0.5953 \tag{8}$$

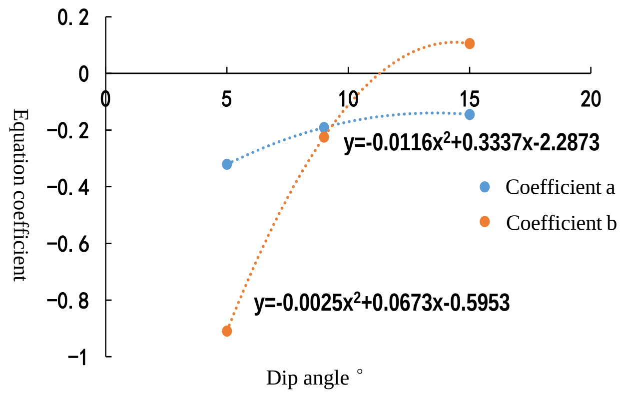

Figure 7. The relationship between the coefficients a, b and the strata dip angle

Therefore, for the actual reservoir, the formation dip and displacement velocity are known, so using the above method can calculate the interface morphology factor. It can be used to judge whether the oil-gas interface morphology is reasonable under different development conditions. If unreasonable, it can be adjusted accordingly.

5. Conclusion

The one-dimensional displacement test was used to clarify the change law of oil-gas interfacial migration during the development of gas-cap expansion energy flooding, and to quantitatively characterize the relationship between oil-gas interface morphological factors and displacement velocity Also we know that there is a logarithmic relationship between oil-gas interface morphological factors and displacement velocity.

Based on the same displacement velocity, with the increase of the displacement dip angle, the morphological factors of oil-gas interfacial increase, indicating that the higher the dip angle of the formation, the more stable the oil-gas interface. When the displacement dip angle is the same, with the increase of the displacement velocity, the morphological factors of oil-gas interfacial decrease, and the oil-gas interface becomes more unstable. It is helpful to rationally utilize the expansion energy of gas cap and improve the overall development of oil reservoirs with gas cap by studying the changes of oil-gas interface morphology under different dip angle and displacement velocity.

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