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Effect of Gas-wetness on Gas-water Two-phase Seepage in Visual Microscopic Pore Models

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Abstract: Theoretical analyses and experimental results show that gas wettability plays an important role on gas-well production. In the study, the gas-wet ability parameter of gas vs. liquid ζ_{G-L}, calculated from the proposed formula in the sessile drop method, used to measure gas wettability of microscopic pore models treated by fluorocarbon polymer Zonyl8740. Following that, the effect of gas-wetness on gas-water two-phase seepage in models was studied by stereomicroscope with a camera. Research results show that, under the condition of the pore structure is constant and displacement velocity is very slow, capillary force is the main motivation for two-phase seepage, and gas wettability has a crucial influence on gas/water interface, displacement characteristics, and distribution of gas and water. It is valuable for development of water flooding gas reservoirs.

Keywords: gas-wetenss, gas-water two-phase seepage, visual microscopic pore model, microscopic seepage mechanism, water flooding gas reservoir.

1 Introduction

The study on gas-water two-phase microscopic seepage mechanism in porous media is the theoretical foundation to develop water flooding gas reservoir. Wettability is an important factor of physicochemical properties of porous media surface and has a remarkable influence on gas-water two-phase microscopic seepage in gas reservoirs. At present, the two-phase seepage mechanics on pore level is mainly for oil reservoirs. But, there is little study on the effect of gas-wetness on gas-water two-phase microscopic seepage mechanics in water flooding gas reservoirs. And the studies are mainly about the influence of pore structure, injection rate on gas-water microscopic seepage mechanism [Zhu, Zhou, and Wan (2004); Amiell,

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Billiontte, and Meunier (1989); Zhou, Li, and Zhang (2002); Sohrabim and Danesh (2001)]. Therefore, the effect of wetness of porous medium on gas-water microscopic seepage mechanism is very important for the development of water flooding gas reservoir.

According to Amott's definition about wettability, which is wetness is defined as: the tendency of one fluid to spread on or adhere to a solid/fluid interface in the presence of other immiscible fluids [Amott and Member (1959)]. Wetness of porous medium is usually evaluated quantitively by the contact angle method in "oil-water-rock" systems [Johnson and Dettre (1969)]. In 2000, Li, K put forward the concept of "gas wetness". He has achieved gas-wetness on the core surface treated by fluorocarbon polymer in porous media [Li and Firoozabadi (2000)]. And Theoretical analyses and experimental results show that gas wettability affected greatly gas well production [Li and Firoozabadi (2000); Wu and Firoozabadi (2010)].

In the study, we first made the microscopic glass network models by UV photoetching followed by Hydrofluoric Acid Corrosion. Secondly, we treated the models by various concentration fluorocarbon polymer (Zonyl 8740) solutions. Lastly, the effect of gas-wetness on gas-water microscopic seepage mechanism such as the interface, migration and distribution of gas-water was studied.

2 Experiment Theory

2.1 Gas-wettness Quantitative Measurement

Sessile drop was used for gas-wettness quantitative evaluation. Microcosmically spreading of the liquid drop is a process of displacing gas by liquid while macroscopically it is a wetting process of liquid against gas on the surface. The bigger the contact angle through the liquid θ_L is, the weaker the wetting ability of liquid against gas will be or the stronger the wetting ability of gas against liquid on the solid surface. Thus the gas-wet ability parameter ζ_{G-L}characterizing wetting ability of gas against liquid is presented in Eq.1. The relationship between gas-wetness andζ_{G-L} and θ_L is shown in Fig.1. As is shown in Fig.1, the range of ζ_{G-L} is [-1,1] . Moreover, with the increase of $\theta_L$andζ_{G-L}, the gas-wetting ability strengthens gradually.

$$\zeta_{G-L} = \cos(\pi - \theta_L) \tag{1}$$

2.2 The Effect of Gas-wetness on Gas-water Seepage in Porous Media

Gas-liquid two phase seepage in porous medium is mainly affected by pore structure, driving pressure, viscous force, capillary force and gravity [Huang and Yu

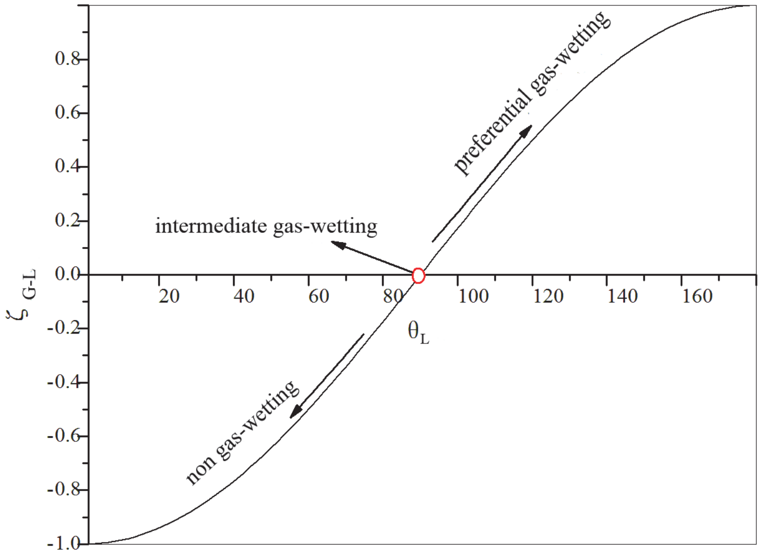


Figure 1: Relationship between gas-wettability, ζ_{G-L} and θ_L

(2001)]. In the study, ideal glass network models with constant pore structure were placed horizontally to guarantee that gas and water seepage would not be influenced by gravity and pore structure. When driving pressure is very low, two phase seepage is mainly affected by capillary force, while when it is somewhat high, major influence parameters turn into driving pressure and viscous force [Huang and Yu (2001)]. According to formulation of capillary force (Eq.2):

$$P_c = \frac{2\sigma\cos\theta}{r} \tag{2}$$

Where, r is pore radius, $\sigma$is surface tension, and θ is contact angle. In order to investigate the influence of wetness on two phases seepage in the microscopic model, Core Power peristaltic pump was used for trace injection (0.3mL/h). At such slow rate, capillary force the primary factor in the seepage: When the liquid is wetting phase, capillary is the driving force. While the liquid is non-wetting phase, capillary is the resistance, and only when the driving force exceeds the capillary force would the liquid begins to seepage. So, influence of wetness on gas and water microscopic seepage could be studied through the experiment.

3 Experiment Process

3.1 Microscopic Model Preparation

Etched glass network model was made by EUVL [Zhu and Qu (1989)]. Pore structure and size are shown in Fig.2. The size is: nine lateral and eight longitudinal capillaries, which were orthogonal, containing 72 relation panel points. Guiding groove lies in the sides of model, which was designed for uniform injection. The thicker capillaries in the middle have 0.2mm in throat diameter and 0.922mm in pore diameter. Symmetrical pores on either side has 0.12mm in throat diameter and 0.5mm in pore diameter. Except the guiding groove, the rest area of pore in the whole model is 32.36mm^2.

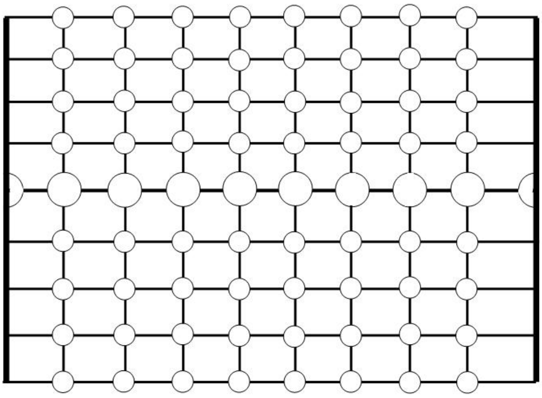


Figure 2: Schematic plot of etched glass network model with ideal pore structure.

3.2 Treatment on Wettability of Microscopic Model

The microscopic models were vacuumed and saturated by different concentration of Zonyl8740(0.05wt%, 2wt% and 10wt%) solutions, and aged for 24h. Next, the liquid was driven out from the model by high pressure nitrogen and dried at 80°. The models treated were prepared for use.

3.3 Gas-wetness Measurement for Microscopic Models

The glass slides which had the same material as models were directly corroded by hydrofluoric acid for the same time as model preparation process. Following that, they were immersed under various concentrations of Zonyl8740 solutions for 24h and then dried. In the study, gas-wetness of the slides were measured by the sessile drop method and used as that of models treated by the same solution.

3.4 Displacement Experiments in Microscopic Models

In the study, air was used as gas phase, and distilled water colored with methylene blue as water phase. The water was injected into the models to drive gas slowly at 0.3mL/h by peristaltic pump. Gas/water distribution and displacement performance were recorded by stereomicroscope with a camera during and after the process.

4 Results and Analysis

4.1 Gas-wetness Quantitative Evaluation of Models

Gas wettability of three models is measured by the sessile drop method and the results are shown in Fig.3. As shown in Fig.3, with the increase of the Zonyl8740 solution concentration, gas wettability of the models treated by them becomes stronger. Treated by 0.05% Zonyl8740 solution, the model appeared non gas-wetnesss (ζ=-0.44). While one treated by 2% was nearly neutral gas-wetness (ζ=0.082 $\approx$0), and the one treated by 10% was preferential gas-wetness (ζ=0.28).

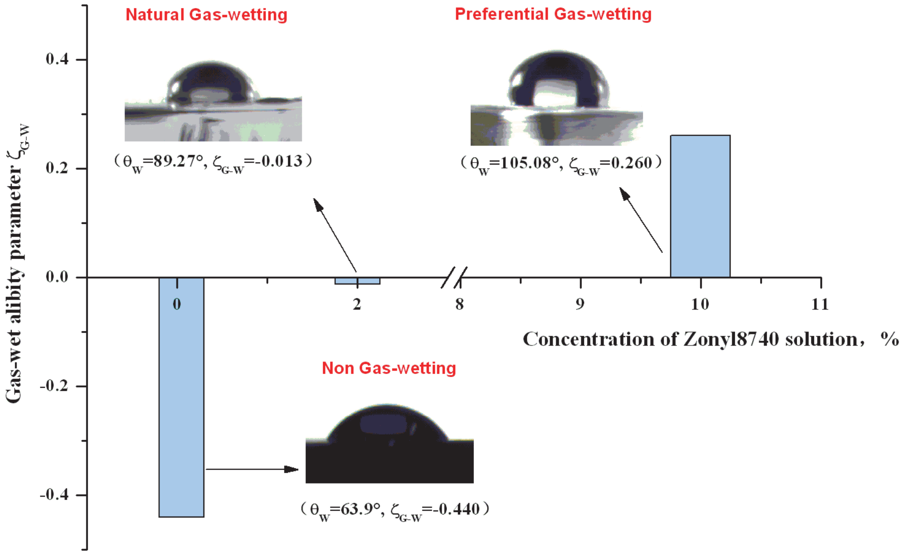


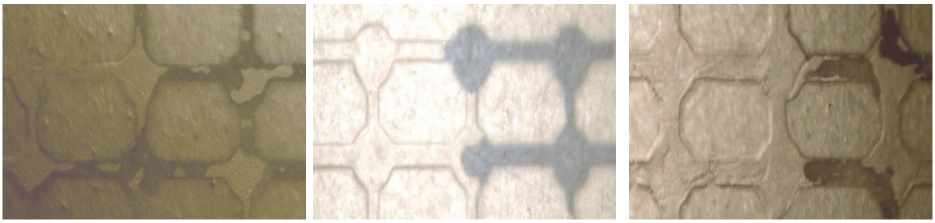
Figure 3: Gas-wetness measurement of microscopic models.

4.2 Effect of Gas-wettability on Gas and Water Seepage Performance

(a) Non gas-wet model: As soon as the water entered the guiding groove in the model, the water imbibition took place. And the water broke through the model along the pore wall. Displacement of gas by water is non-piston. Gas-water displacement front presents a meniscus and water is the concave, as shown in Fig.4 (a).

(b) Neutrally gas-wet model: As Fig.4 (b) shown, in the neutral gas-wet model, water displaced gas uniformly and the displacement is pistion-like. Gas-water interface of displacement front is flat and the capillary force is zero.

(c) Preferentially gas-wet model: As shown in Fig.4 (c), in the preferentially gas-wet one, water flowed at the center of pore-throat. Gas-water interface of displacement front is in meniscus shape and water is convexity. It is obvious that there is a layer of gas along the pore wall.



(a) Non gas-wetness (ζ=-0.44)

(b) Neural gas-wetness (ς =0.082≈0)

(c) Preferential gas-wetness (ς =0.28)

Figure 4: Effect of was-wetness on displacement performance.

4.3 Effect of Gas-wetness on Gas-water Distribution and Gas Recovery

(a) Non gas-wetness model: As shown in Fig.5 (a), water flooding gas is mainly governed by capillary force in the non gas-wetness model. In the intersection, the radius becomes bigger and that leaded to reduction in capillary force and much air is trapped there. As the process went on, water dragged air into the throat and the air bubble was lengthened or broken up into air bubble which is distributed in the model. In the wall, there is a layer of water and even water droplets. In the case, gas recovery by water displacement is relatively low.

(b) Neutral gas-wetness model: In the model, gas displacement efficiency is the highest among the three gas-wet states. The model is almost full of water and there is little air in it, as shown is Fig.5 (b).

(c) Preferential gas-wetness model: As shown in Fig.5(c), in the preferential gas-wet one, water was located in the center of pore. There is a layer of gas adhering to the wall. In the case, gas recovery by water displacement is the lowest.

(a) Non gas-wetness (b) Neural gas-wetness (c) Preferential gas-wetness

Figure 5: Effect of gas-wetness on gas-water distribution and gas recovery.

5 Conclusions

(1) Gas-wettability quantitative measurement method has been established by use of the sessile drop method in the gas-water-solid systems.

(1) In the non gas-wet model, various water imbibition took place and the displacement is non piston-like. Gas-water displacement front is meniscus in shape. water is the concave and flows along the pore wall. There is much gas trapped in the model. In the case, gas recovery is relatively low.

(3) In the neutrally gas-wet model, the waterflood gas is piston-like. Gas-water interface of displacement front is flat. Though displacement velocity is low, gas recovery by water displacement is the highest.

(4) In the preferential model, water is always flow in the center of the pore in the process of displacement. There is a layer of gas adhering to the pore wall. In the case, gas recovery is the lowest among the three models.

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