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Study on the Experimental Technology of the Ultra-Low Permeability Reservoir Well Group Physical Simulation

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Abstract: In this study, we have a study on the experimental technology of the ultra-low permeability reservoir well group physical simulation. Realized the physical simulation of a complete well group of the actual oil field for the first time, overcoming the technical problems of the model making and the saturation measuring. Formed an integral experiment method for the physical simulation experiment of the ultra-low permeability reservoirs. Provide a new experimental method for the production forecasts of the ultra-low permeability reservoirs.

Keywords: Resistivity method, sandstone outcrop, saturation distribution ultra-low permeability reservoirs, well group physical simulation

INTRODUCTION

In the past 10 years, the ultra-low permeability reserves accounted for a big proportion in our countries proven oil reserves and the undeveloped reserves, there are more and more ultra-low permeability oil field being developed (Li, 2003). According to the similarity theory, the oil field can be zoom out into flat model according to certain scaling, each production index can be zoom in or zoom out to a certain proportion of the scale according to the similarity criterion.

Through the flat model by some production scheme for development, one can complete the developing process of an actual oilfield with a relatively short period of time, so as to achieve the purpose of forecasting development result. Further more, with flat model Physical simulation one can realized a variety of development schemes with relatively small cost and so that we can have advises of reasonable development programs. Due to the limitation of the laboratory condition, at present there is no reports of well group physical simulation. The existing simulation experiment laid particular emphasis on the high permeability reservoir research, which adopts artificial sandstone model, choose well pattern unit to simulate (Guan *et al.*, 1997, 2009; Li *et al.*, 2008; Lan *et al.*, 2006; Qin *et al.*, 2000; Wang *et al.*, 2002, 2005; 2007; Xu *et al.*, 2007). As the pores and throats of the ultra-low permeability reservoirs are tiny, we cannot make a sand-packed model which has the same permeability. That hindered the way to study the seepage rule of fluid flow in the ultra-low permeability reservoirs through experimental method. We use the sandstone outcrop plate model to do the experiment, which has the same pore structure as the real reservoirs do. Perform the fluid displacement experiment in them can reflect the rules of fluid flow in the real reservoir to the greatest extent. The change of the saturation distribution in the process of displacement can be measured through the resistivity method, which can provides experimental support for the prediction of the remaining oil distribution.

In this study, we have a study on the experimental technology of the ultra-low permeability reservoir well group physical simulation. Realized the physical simulation of a complete well group of the actual oil field for the first time, overcoming the technical problems of the model making and the saturation measuring. Formed an integral experiment method for the physical simulation experiment of the ultra-low permeability reservoirs. Provide a new experimental method for the production forecasts of the ultra-low permeability reservoirs.

WELL GROUP PHYSICAL SIMULATION EXPERIMENT METHOD AND EXPERIMENTAL DEVICE

Well group field data: The selected well group first take inverted nine spot water flooding pattern with the well spacing is 250-300 m, then it was refined into the irregular one (Fig. 1). Among them, W5 is the injection well, the rest 8 Wells are producing wells. The average

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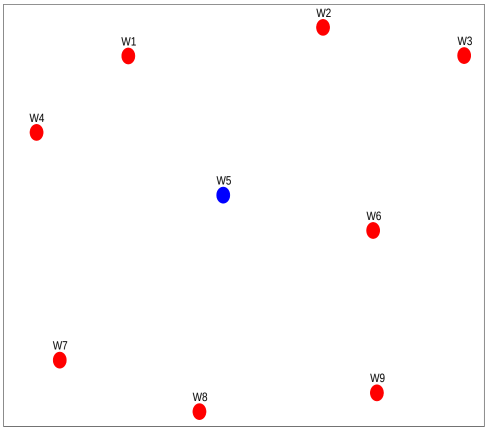


Fig. 1: Well pattern of the actual oil field

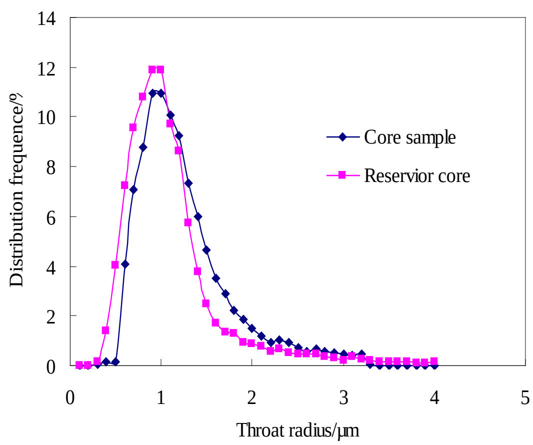


Fig. 2: Throat radius distribution contrast curve between the outcrop core and the actual oilfield ultra-low permeable reservoir core

permeability of this reservoir is $3.02\times10^{-3}\mu m^2$, the average porosity is 13.3%, the original oil saturation is 56.1%, reservoir temperature is 44.2°C, the original formation pressure is 9.13 MPa, underground crude oil viscosity is 1.96 mPa/s.

The experiment model making: For the similarity of the experimental model and the reservoir, the natural outcrop sandstone was chosen to be the experimental model. Drill the core samples from the outcrop sandstone, using the mercury injection apparatus to test the core samples to have the message of throat radius distribution, test results were shown in Fig. 2. Through the contrast, it can be found that the radius distribution of the natural outcrops sandstone and the actual oilfield reservoir throat is very close. We use the sandstone outcrop plate model to do the experiment, which has the same pore structure as the real reservoirs do. Perform the fluid displacement experiment in them can reflect the rules of fluid flow in the real reservoir to the greatest extent.

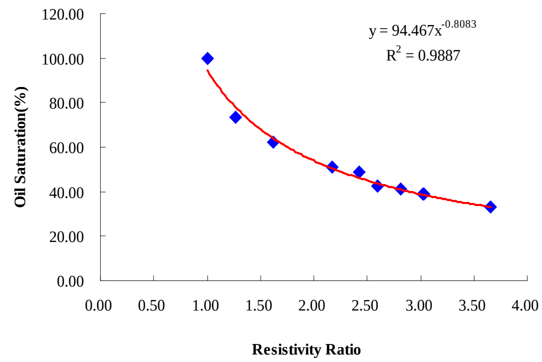


Fig. 3: Saturation calibration curve

According to the principle of Lorenz curve method (Zhu *et al.*, 2009), Permeability variation coefficient is between 0 and 1, the smaller the permeability variation coefficient, the more homogeneous the reservoir is. Drill 8 core samples from the ultra-low permeability outcrop with the diameter of 2.5 cm, including 4 piece of horizontal and 4 piece of vertical direction, take the core samples to do the experiment to get the gas permeability, water permeability and porosity (Xue, 2011), Choose the relatively homogeneous plate model as the experimental model.

According to the actual oilfield well group injection-production well positions to make the experimental model, finally we made the flat model with the size of 50 cm×38 cm×3cm. In one side of the flat model the injection-production well and pressure measuring point are arranged, the fracture was made to simulate the hydraulic fracturing of the producing well. In the other side of the flat model the measuring electrode was Decorated used for the measurement of oil saturation in the process of the experiment using the method of resistivity.

The Model was capsulated using special resin materials; the interface was directly packaged to the model, which can guarantee the strength and sealing of the model. The model can be used in the experiment with the pressure environment of 25 MPa.

Saturation calibration method:

- Vacuum the core samples and saturated them with certain concentration of salty water, measured their resistance respectively
- Put the core samples in series in the same core holder, displace it with oil
- Have the above core samples with different oil saturation degree to do the Nuclear Magnetic Resonance (NMR) measurement, determine the oil saturation of each core sample and record the resistivity respectively Saturation calibration curve (Fig. 3) can be obtained by Statistic the measurement data.

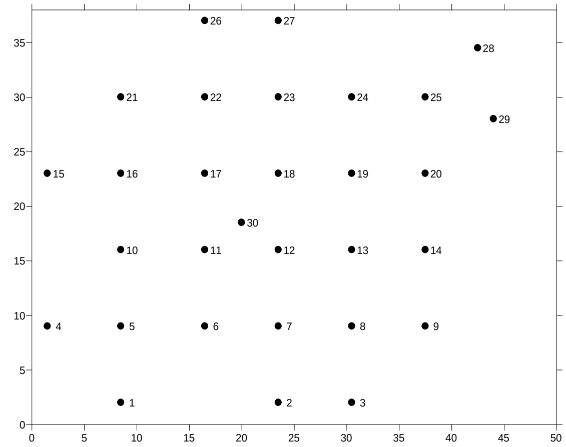


Fig. 4: Resistance measurements electrode distribution

Saturation measuring method: The measurement electrodes were decorated in the back of the flat model, According to the saturation calibration curve, by measuring the resistance of the two electrode points, the resistance ratio of the two points can be obtained, then the oil saturation can be back calculated, by which one can analysis the displacement front and displacement process. The experiment model measuring electrode distribution is shown Fig. 4.

The experiment steps: The Well group physical simulation experiment was preceded in the following steps:

- Vacuum the model and saturated it with formation water, oil flooding the model to made bound water.
- Perform the well group physical simulation experiment using the same production scheme as the actual oilfield well group, record the oil and water production data and measured oil saturation distribution in different period of the displacement.

Experimental apparatus: The well group physical simulation experiment was performed in the large outcrop model experiment system, The experiment system is made of a displacement system, casing pressure system, resistivity measurement system, pressure measurement system, autoclave, automatic open loop system, vacuum saturation system, experiment model and autoclave protection system. For the well group physical simulation experiment needs to simulate at least one complete well group, so a relatively large autoclave is necessary. Large outcrop model experiment system is designed and manufacturede specially for the experiments of large outcrop model, the volume of high pressure environment it can provide meet the present needs of well group physical simulation. Figure 5 shows the large scale outcrops model experiment system.

Fig. 5: Large scale outcrops model experiment system

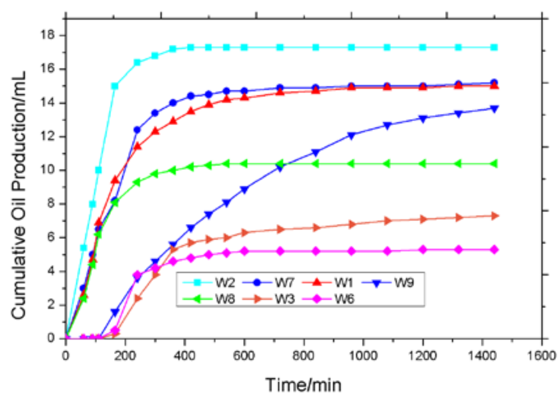


Fig. 6: The single well cumulative production curve

THE EXPERIMENTAL RESULTS AND ANALYSIS

Draw the single-well cumulative oil production curve according to the production data as shown in Fig. 6. From the single well cumulative oil production curve we can see that, well W2, well W7 and well W1 have relatively high oil production, oil production of all wells can be visualized from the single well cumulative production curve.

Well W2 is a production well which was nearest to the injection well, so it had the fluid production first and had high oil production rate.

The cumulative oil production curve of well W1 and W7 are similar, well W1 is due to close to the injection well, it take effect fast; although well W7 is far away from the injection well, the extension of the fracture make the cumulative oil production curve has the similar rules as well W1 do.

The distance between the injection well and well W8 is almost the same with the distance between the injection well and well W7, because of the high oil production rate, there are more oil produced from well W7, which makes the oil production of well W8 was relatively poor.

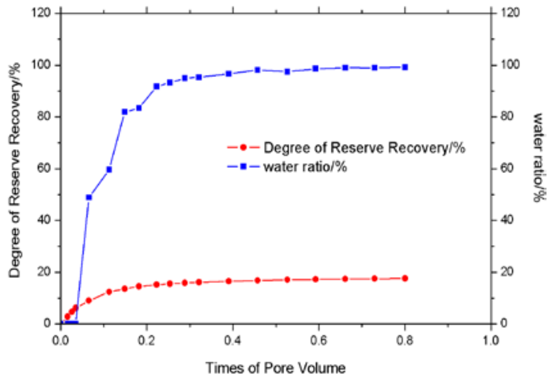


Fig. 7: Dynamic figure of the well group production

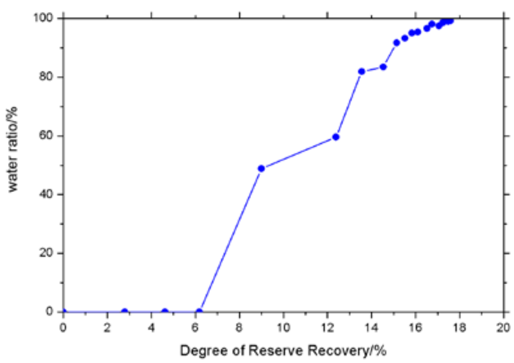


Fig. 8: Water ratio degree and reserve recovery relation curve

The distance between the injections well and well W6 is almost the same with the distance between the injection well and well W3, the cumulative oil production curve of well W6 and W3 are similar, the hydraulic fracture from well W3 make a better connection with the injection well, so it has more oil production.

Well W9 is farthest from the injection well , so it take effect at last, because the pressure sweep lag, for a long time, it had a certain rate of oil production without water production.

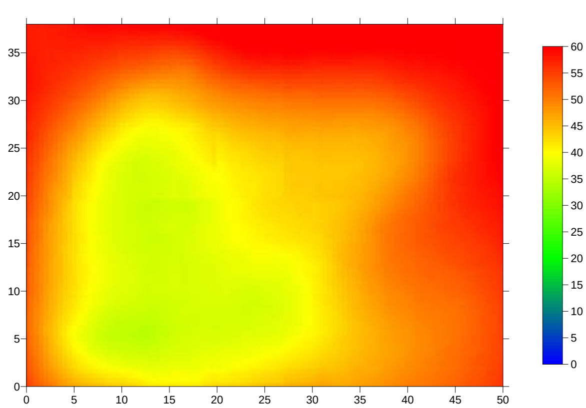
From the Dynamic figure of the well group production, we can see that in the well group physical simulation experiment, when the injected water volume achieves 0.5 pore volumes, the oil recovery was nearly 20%, at this time, as the displacement went on the oil recovery no longer increase. From the well group physical simulation experiment we know that the oil recovery of water flooding is 20%. The experiment has similar production rules as the actual oil field do. We can predict from the physical simulation result that when the injected water volume achieves 0.5 pore volumes, the oil recovery is hard to increase if there are no stimulation measures and the water ratio is quickly reached 100%. Figure 7 shows the dynamic figure of the well group production.

From the Water ratio degree and reserve recovery relation curve (Fig. 8) we can see that, the reserve recovery of the well group in water free oil production period can reach 6%, for the reserve recovery from 6%-12% was produced in the condition the water ratio below 60%, in this period of time the water ratio will increase rapidly, so it is right time to take some measures to control the water ratio increasing and maintain the stable yields. Figure 9 shows the oil saturation field figure of different flooding stage.

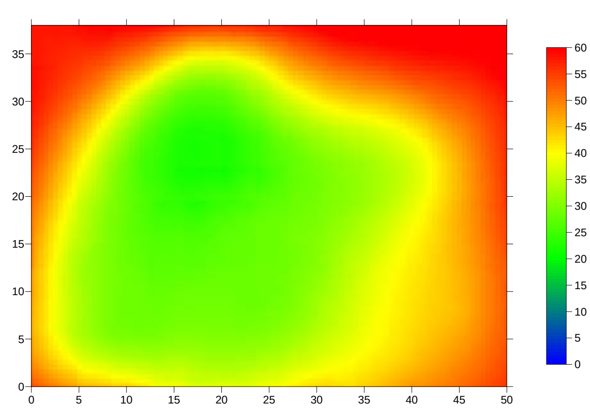
The saturation distribution of the model was monitored in the experiment process using the above experimental equipment and then we have the oil saturation field figure of different flooding stage as follows:

From the oil saturation field figures we can see the process the oil was produced from the model, the whole flooding process was finished in between 14 hours. From the final oil saturation distribution we can see that the hydraulic fracture reformed the porous media, there is better flooding effect and relatively high oil displacement efficiency along the hydraulic fracture.

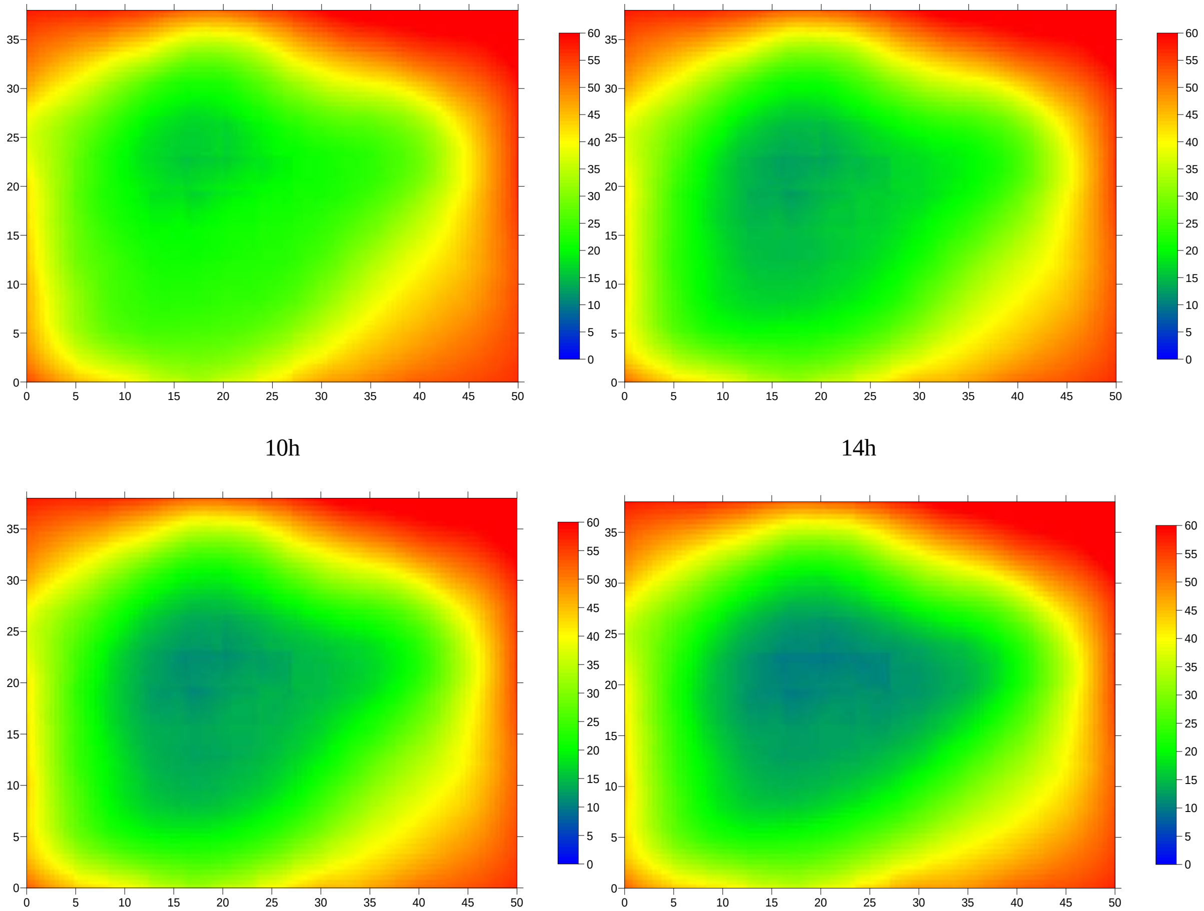
After 14 h of water flooding, the water ratio of the well group was almost 100%, there is little change of the oil saturation field, the oil displacement efficiency has little increase, most of the injection water displace in the advantage channel, that means the remaining oil in the model was hard to be extracted if there is no stimulating measures.



2h



6h



10h 14h

18h 22h

Fig. 9: Oil saturation field figure of different flooding stage

CONCLUSION

- Well group Physical simulation experiment of the ultra-low permeability reservoir use the sandstone outcrop plate model to do the experiment, which has the same pore structure as the real reservoir do. Perform the fluid displacement experiment in them can reflect the rules of fluid flow in the real reservoir to the greatest extent.
- A set of sandstone outcrop screening method was formed, which solves the model making problems in the physical simulation experiment.
- A set of saturation calibration and measurement experimental method was formed, which solves the saturation field measurement problem in the physical simulation experiment.
- An integral experimental method for the physical simulation experiment of the ultra-low permeability reservoirs was formed, which provide a new experimental method for the production forecasts of the ultra-low permeability reservoirs

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