Energy Proceedings
Vol 27, 2022
ISSN 2004-2965

Degassing Process and Water-flooding Oil and Gas Mechanism of Cores with Different Fracture Occurrences in Weakly Volatile Carbonate Reservoirs

Hongxin Guo [1,2], Linsong Cheng [1,2*], Pin Jia [1,2], Peng Wang [1,2]

1 State Key Laboratory of Petroleum Resources and Prospecting, China University of Petroleum (Beijing), Beijing, 102249

2 College of Petroleum Engineering, China University of Petroleum (Beijing), Beijing, 102249

ABSTRACT

The weakly volatile crude oil in the carbonate reservoir is easily degassed when the pressure is reduced. In this paper, weakly volatile oil with similar dissolved gas-oil ratio to actual oil field was prepared, and three fracture occurrences carbonate cores were designed. The self-designed oil-gas-water three-phase metering device was used to accurately measure the flow. The research results showed that GOR presented three stages: rising stage, falling stage and steady rising stage. For the GOR of low-angle through fracture core, the peak value is the highest during water injection. In studies of different depletion degrees, an appropriate degree of degassing not only effectively utilizes the elastic energy of the gas, but also reduces the development cost of the oil field.

Keywords: weakly volatile oil reservoirs, fracture occurrence, degassing process, oil-gas-water three-phase fluid flow

1. INTRODUCTION

Weak volatile fractured reservoir, due to its complex well-developed fracture, various angles of fractures affect the water flooding law, and also led to formation heterogeneity. At the same time, for weak volatile reservoirs with small gap between formation pressure and bubble point pressure, oil-gas-water three-phase seepage generally occurs in water flooding step, which makes the fluid flow mechanism very complicated. For the experimental study on water flooding mechanism of weak volatile fractured reservoirs, two experimental conditions need to be overcome. One is the preparation of weak volatile oil, and the other is the preparation of cores with different fracture occurrences. In order to achieve the appropriate level of degassing, it is necessary to accurately control the pressure in the experimental process. Then, the oil, gas and water three-phase production data are measured by displacement experiment to analyze the law of water flooding. The experimental study on water flooding mechanism of weak volatile fractured reservoirs is very difficult, and there are few related studies. It is urgent to carry out water flooding oil and gas experiments, which is of great significance to improve oil and gas production in such reservoirs.

In the process of water flooding in fractured reservoirs, the influence of fractures on water flooding law is obvious. Through the combination of seismic data, geological data, rock physical properties, reservoir data and drilling and production data, detailed matrix and fracture description are generated (Hillgartner et al., 2011[1]). Prediction of water flooding displacement effect based on accurate geological model, Pavel Dmitrievich Gladkov et al.[2] predicted the water flooding effect of fractured reservoirs by hydrochemical monitoring method, Juan Gerardo del Ángel Morales et al.[3] used the fluid flow information of borehole images, acoustic data and NMR logging data to predict the remaining oil saturation of fractured carbonate reservoirs. Various occurrence fractures in fractured reservoirs affect the characteristics of water flooding. On the one hand, numerical simulation is used to study different mobility ratio, fracture positions, and single sand positions (Murata et al., 2014[4]; Volgin, 2008[5]; Li et al., 2015[6]). On the other hand, through experimental research, Qu et al.[7] designed a three-dimensional visual physical model of fractured-cave carbonate core and carried out different flooding methods such as bottom water flooding, water flooding and gas flooding. It was found that fractures were more easily to water breakthrough than caves, and even serious water breakthrough. Therefore, Alhuraishawy et al.[8] developed a coupling of low salinity water flooding and preformed particle gel to enhance recovery in fractured reservoirs. Li et al.[9] used streamline simulation to optimize the dynamic water injection process of fractured reservoirs, reflected the changes of fluid flow pattern and well drainage information in the reservoirs, and improved the water injection efficiency. On the contrary, the water injection process will also have an impact on the fracture propagation. The water injection displacement increases pressure, the hydraulic fracture will redirect, and the capillarity phenomenon will also change dynamically (Kuzmina et al., 2009[10]; Li et al., 2019[11]).

For weakly volatile oil reservoirs, the properties of crude oil determines the development system. An important issue is to accurately predict the production of weakly volatile reservoirs. Makinde et al.[12-14] used the decline curve analysis method (DCA) and a data-driven principal component method (PCM) to accurately predict the production of shale volatile reservoirs considering the component model. Most studies on the properties of weakly volatile crude oil need to be carried out indoors. First of all, it is necessary to prepare weakly volatile oil similar to the reservoir, which is called live oil below. Many scholars used nuclear magnetic resonance technology to study the properties of live oil. Based on T_2 spectrum and other data, the interpolation function was used to map to viscosity, gas-oil ratio and other properties of live oil (Anand et al., 2009[15]; Sullivan et al., 2015[16]; Chen et al., 2010[17]). Another important property of live oil is the phase behavior study. Based on the live oil sample, Cardoso et al.[18] obtained the phase behavior of the live oil by using the high-pressure microscope and the isothermal depressurization experiment. To obtain the water flooding law of live oil reservoir, Moreno et al.[19] used ultra-long unconsolidated cores to saturated live oil, and studied remaining oil saturation. Mishra et al.[20] obtained gas production velocity profile by core displacement experiment.

In this paper, according to the properties of crude oil in actual oilfield, the live oil with specific dissolved gas-oil ratio was prepared according to the similarity criterion. Through core displacement experiment in depletion stage and water injection stage, the gas saturation was similar and the flow of oil, gas and water was accurately measured. Based on the experimental data, the change of GOR and water cut under the influence of different fracture occurrences were analyzed, and the law of water flooding oil and gas was summarized. In addition, five comparative experiments were carried out to optimize the injection timing of weakly volatile reservoirs, and the influence of gas phase on fluid flow was summarized and discussed. The above research has good theoretical guiding significance for weakly volatile fractured reservoirs.

2. LIVE OIL PREPARATION AND WATER FLOODING EXPERIMENT

2.1 Preparation of live oil with specific dissolved gas-oil ratio

The original formation pressure is 24.1 MPa, and the bubble point pressure is 21.0 MPa. The crude oil in this reservoir has weakly volatility and small difference between formation pressure and bubble point pressure, and the formation pressure is lower than the bubble point pressure at present. To improve oil recovery and increase formation energy, the target oilfield adopted water injection. The formation fluid is characterized by oil, gas and water fluid flow, and the flow mechanism is complex.

According to the properties of crude oil in the target area, this experiment prepared weakly volatile oil, also known as live oil. Through the preparation of live oil with similar fluid properties to the target area, combined with core displacement experiment, the fluid flow law in the two stages of depletion development and water injection development was reflected.

According to the laboratory conditions and properties of crude oil in the target area, the dissolved gas-oil ratio of live oil is 30 m^3/m^3. Anhydrous kerosene and CO_2 were used as experimental materials for preparation of live oil. The two were fully mixed under high pressure by using a high-pressure sampler. The numerical simulation showed that kerosene and gas could be fully integrated at room temperature under 6 MPa. To achieve the same properties of the live oil used in each group of experiments, the prepared live oil needs to reach the same dissolved gas-oil ratio. By determining the kerosene volume and total gas flow, and using the sampler to fully integrate, the live oil with specific dissolved gas-oil ratio was prepared. The main steps are as follows (Fig. 1):

1) 1L kerosene was poured into the sampler and injected with 30L CO_2.

2) Water injection at the bottom of the high pressure sampler increased the pressure of the cavity to more than 6 MPa.

3) Opened the swing button and constantly swing the sample for two days to fully mix oil and gas.

4) The prepared live oil was transferred from the sampler to the intermediate container using a back pressure device.

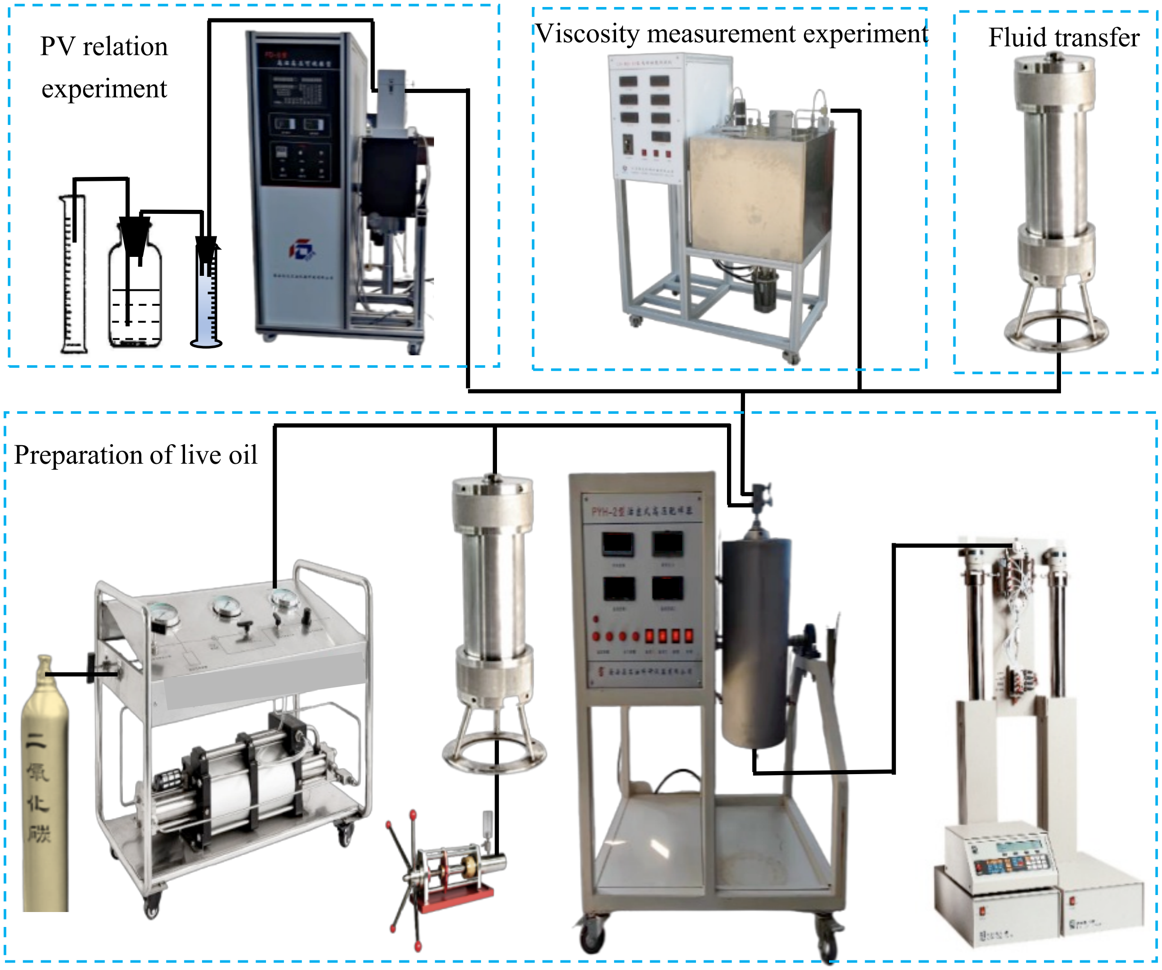


Fig. 1 Preparation of live oil and determination of its properties

2.2 Water flooding oil and gas experimental platform and experimental steps

Oil-gas-water metering device. In the process of displacement experiment, it is necessary to obtain the oil, gas and water data for the analysis of GOR and water cut. In this paper, through the self-designed oil-gas-water metering device (Fig. 2), the cumulative oil-gas-water production change in the depletion stage and the water flooding stage can be measured in real time. The oil-gas-water metering device connects the back-pressure valve, and the three-phase fluid flows into the A-tube from the back-pressure valve. The A-tube can measure the cumulative water production and oil production at different times. The gas is discharged from the A-tube, increasing the pressure of the beaker, so that the water is discharged to the B-tube, and the water in the B-tube is measured as the gas volume. To reduce the experimental error caused by the delayed effect of gas measurement and gas compression at the beginning of the experiment, the experimental device was connected well to ensure its good sealing, and then the air is injected into the measuring device through terminal pipeline until the B-tube is just flowing out. It should be noted that the gas volume at each time should be equal to the measured gas volume minus the liquid production.

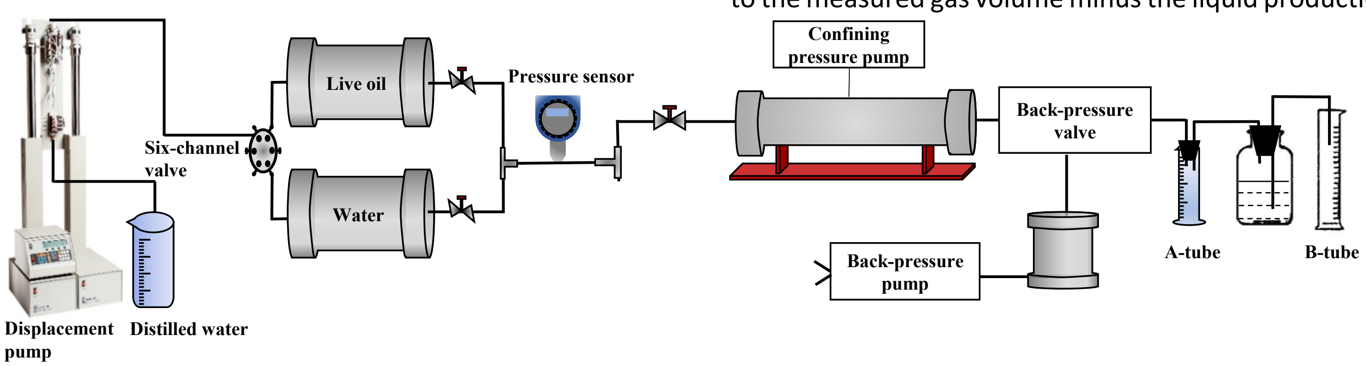


Fig. 2 Diagrammatic drawing of core displacement experimental device

Gas saturation is similar. This experiment included the depletion stage and water flooding stage. A very important issue is the degree of depletion. To achieve the similarity with the target oilfield development, the basis for determining the degree of depletion in this paper was the same as the gas saturation at the end of the depletion development of the target oilfield. By accurately controlling the back pressure, the core can reach a specific gas saturation. The PVT fitting was needed to determine the phase curve of the live oil, and then the degree of depressurization was obtained to achieve the gas saturation. The pressure value was determined, then the pressure of the back-pressure valve was adjusted to that pressure, and the depletion development.

Experimental device and experimental steps. The experimental equipment mainly includes displacement pump, confining pressure pump, core holder, intermediate container, pressure sensor, back pressure control system and oil-gas-water metering device. The diagrammatic drawing of the experimental device is shown in Fig. 2. Using the above experimental device, the experimental steps of water flooding oil and gas were designed:

1) Physical properties measurement of dry core. Dry core quality was weighed by electronic balance, core length and diameter were measured by slide gauge, and permeability was measured by gas flowmeter.

2) Saturated water. Firstly, the core was vacuumized with a vacuum pump, and then the displacement pump was used to inject water at a constant speed of 1 ml/min. When the inlet pressure was stable, the water phase permeability of the core was measured. The core quality after saturated water was weighed and the core porosity was calculated.

3) Live oil flooding, the establishment of irreducible water. The back-pressure valve was connected to the core outlet. By adjusting the back-pressure valve, the pressure was higher than the bubble point pressure. Live oil was injected at a constant speed of 0.5 ml/min. When the inlet pressure was stable, the cumulative water production was recorded, and the irreducible water saturation and oil phase permeability were calculated.

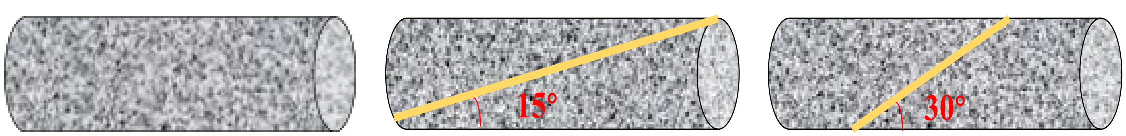
4) Depressurization and degassing. By adjusting the pressure of the back-pressure valve to below the bubble point pressure, the inlet was closed and the depletion production began. When the fluid output at the outlet was small and difficult to accurately measure, the depletion production was stopped and the water flooding was started. Record time, cumulative gas production, cumulative oil production and pressure data.

5) Water flooding oil. Water was injected at a constant speed of 0.5 ml/min. The time, inlet pressure, back pressure, cumulative oil production, cumulative liquid production and cumulative gas production needed to be recorded. When the water came out from core outlet, it was necessary to record the water breakthrough time, cumulative oil production, cumulative liquid production and cumulative gas production, inlet pressure and back pressure. When 30 PV water was injected, the water permeability under remaining oil saturation was measured and the remaining oil saturation was calculated.

3. EXPERIMENTAL RESULTS OF CORES WITH DIFFERENT FRACTURE OCCURRENCES

3.1 GOR

To explore the law of water flooding oil and gas under the influence of different fracture occurrences, this paper carried out three parallel experiments of matrix core, low angle non-through core and low angle through core. The porosity of the core is 12%, the matrix permeability is 30mD, the wettability is neutral and partial water-wet, and there is no water sensitivity. The main minerals are dolomite and calcite. Fig. 3 is the schematic diagram of three types of cores.



(a) Matrix core *(b) Low angle through core* *(c) Low angle non-through core*

Fig. 3 Schematic diagram of cores with different fracture occurrences

Through the water flooding experiment, the cumulative oil and gas production at different times was measured, and the gas-oil ratio (GOR) was calculated, as shown in Fig. 4. Where (a) is the depletion stage, (b) is the displacement stage, and (c) is the overall process.

In the depletion stage, GOR changes show three stages: rising period, declining period and steady rising period. Each stage has the following characteristics: (1) Rising period: This stage changes from discontinuous gas phase to continuous gas phase. When the pressure is lower than the bubble point pressure, the gas is precipitated from the live oil, but at first the discontinuous gas phase is formed. With the decrease of pressure, the gas gradually expand, gather and migrate to form a continuous gas phase, and the gas phase is better than the oil phase to flow out of the core, which increases to the peak. (2) Declining period: This stage is the main oil recovery in the depletion stage, and the gas production decreases. The elastic energy of the dissolved gas precipitated from the live oil displaces the oil from the core, and the oil begins to produce in large quantities at this stage. At the same time, since the back-pressure valve at the core outlet is reduced to below the bubble point pressure at one time and remains unchanged, the gas production is significantly lower than that at the previous stage, and the gas production continues to decline. Finally, GOR decreases rapidly. (3) Steady rising period: At this stage, the oil production decreases rapidly, and the gas production tends to be stable and slightly decreases. The elastic energy of dissolved gas is insufficient. For the gas phase, the gas is still produced in the core, coupled with the dissolved gas in the output oil, which led to a steady increase in GOR.

For the water flooding stages, the GOR increases and then decreases after the water injection, which is because the injected water will replace the gas from the core and increase the GOR. Then, with the increase of core pressure, a part of gas phase is dissolved into oil, resulting in the decrease of GOR.

Fractures with different occurrences also affect the GOR. In the depletion stage, the depletion period of low angle through fracture is the shortest, followed by low angle non-through fracture, and the longest depletion period is matrix core. In the stage of water injection, the peak value of GOR with low angle through fracture is the highest, which indicates that the fracture intensifies the phenomenon of water channeling, and makes the injected water displacing gas along the fracture in a short time, resulting in the rapid increase of GOR.

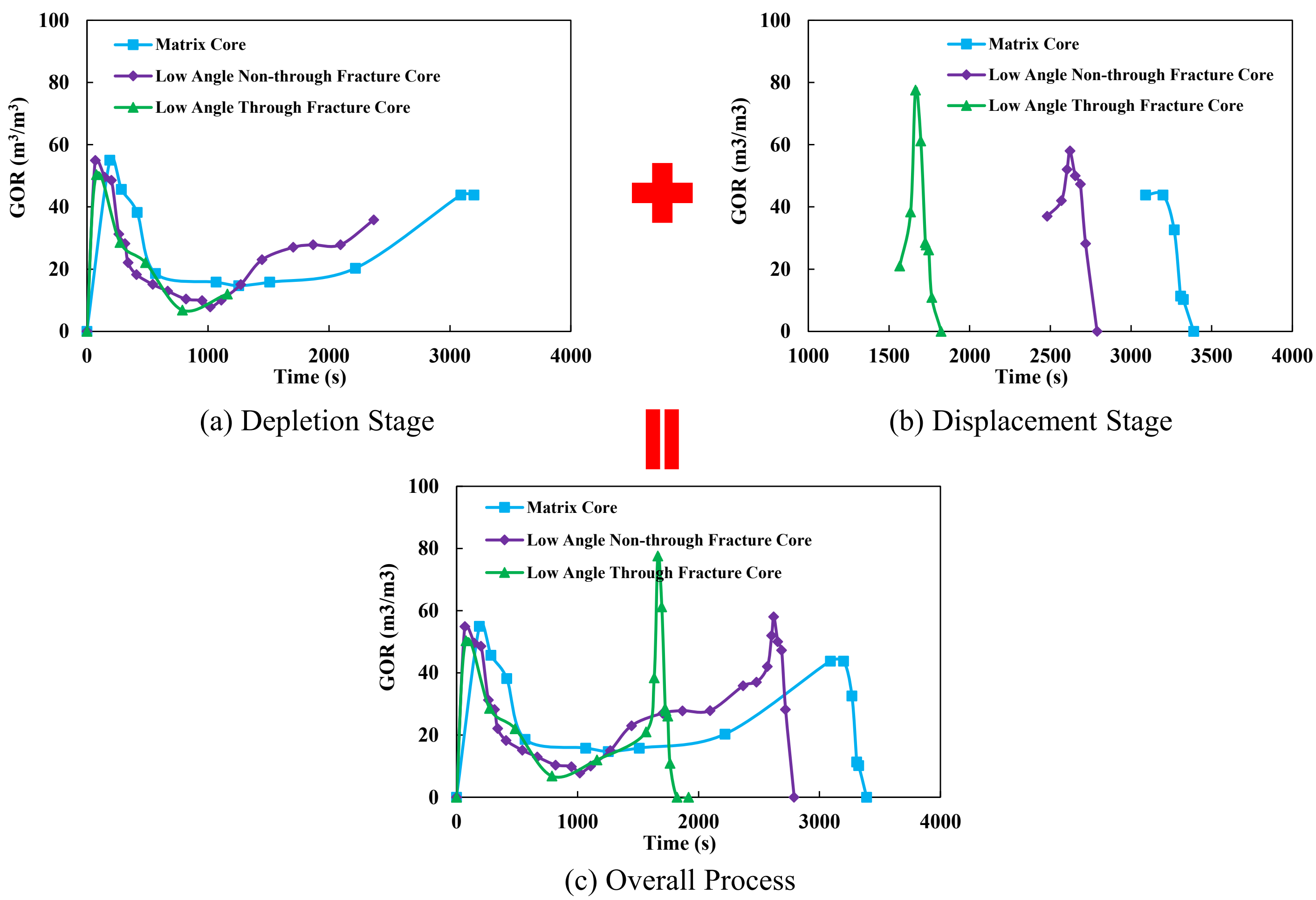


Fig. 4 GOR variation law of cores with different fracture occurrences

3.2 Water cut

The change of water cut reflects the characteristics of water flooding. Water flooding oil and gas experiment has a certain depletion period, Fig. 5 is the curve of water cut including depletion period and water flooding period. It can be clearly seen that the water cut of cores with different fracture occurrences is basically the same, and they all show the “convex” feature, which is characterized by rapid water cut rise and long ultra-high water cut period. From the beginning of water injection to the time of water breakthrough, it is defined as the anhydrous period. The shortest anhydrous period is the low angle through fracture, and the longest is the matrix core. The fracture makes the injected water burst along the fracture, and the water breakthrough time is short. On the contrary, the injection water displacement of matrix core is more uniform, and the water breakthrough time is longer. However, once the water breakthrough occurs at the outlet of the core, the water cut increases rapidly, and almost no oil is produced. However, after water breakthrough, oil production can still be continued in the through fracture, resulting in a slower increase rate of water cut compared with the matrix core.

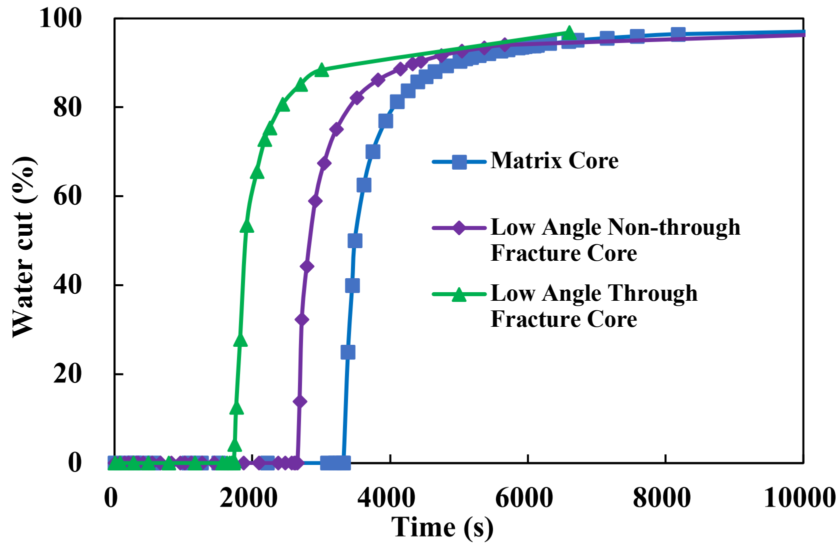


Fig. 5 The variation law of water cut

4. PRESSURE LEVEL OPTIMIZATION

For weakly volatile reservoirs with small gap between formation pressure and bubble point pressure, depletion development is generally adopted first, and then water injection measures are implemented to increase formation energy when pressure drops to a certain level. Therefore, a key problem is to reduce the pressure of depletion development to what extent and then turn to water injection, so that the oilfield development benefit is the highest. This paper designed five schemes: (a) Without depletion stage, direct water injection development; (b) Depletion to bubble point pressure, then water injection development; (c) Depletion to bubble point pressure below 20%, then water injection development; (d) Depletion to bubble point pressure below 40%, then water injection development; (e) Depletion to bubble point pressure below 60%, then water injection development.

Based on the five schemes designed above, a numerical simulation model was established, and oil displacement efficiency curves under different pressure levels were obtained statistically (Fig. 6). It can be seen from the figure that direct water injection and depletion to bubble point pressure have the same final oil displacement efficiency and the best oil displacement effect among all schemes. The greater development degree in the depletion stage, the lower final oil displacement efficiency. However, it is noted that the oil displacement efficiency is only 3.3% lower than that of direct water injection when the depletion to bubble point pressure below 20%. Therefore, considering the economic cost of water injection, reducing the pressure of depletion stage to the appropriate pressure can not only reduce the cost, but also ensure high production. The maximum depletion recovery rate is 30% when the depletion development efforts continue to increase. At the same time, the greater the degree of depletion, the less effect of water injection. Through the above discussion, the appropriate degassing degree can be obtained, and the best control is within 20% below the bubble point pressure, with good development benefit.

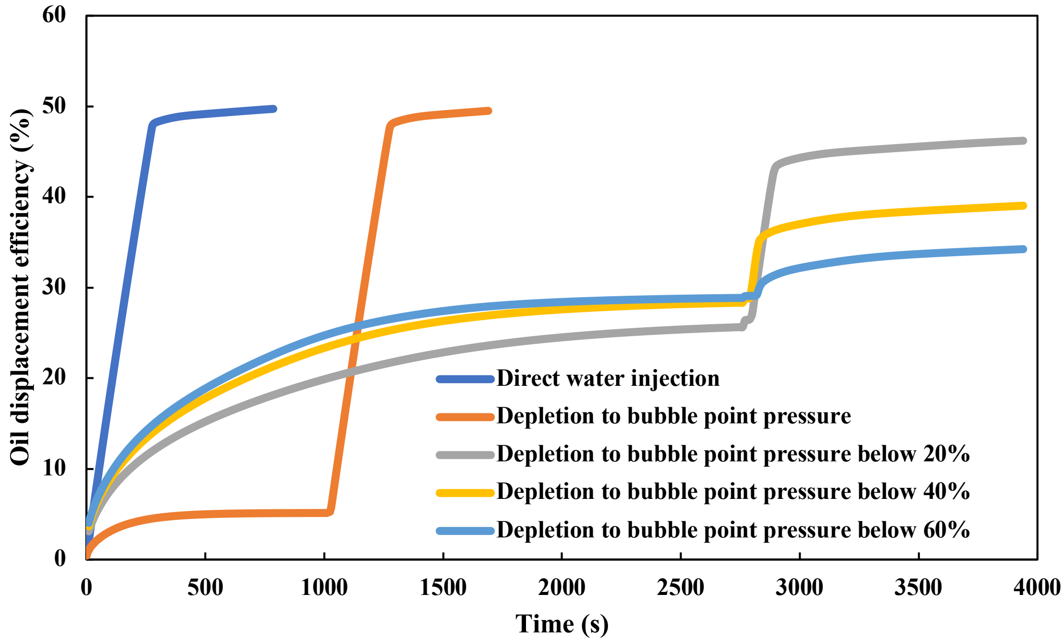


Fig. 6 Optimization of different pressure levels

For weakly volatile reservoirs, if the depletion development drops below the bubble point pressure, gas will be precipitated from crude oil, so how does this precipitation affect development? The favorable side is gas expansion can play a role in increasing formation energy, thus displacing crude oil; The disadvantage is the gas may lock the pore throat, hinder oil phase seepage. Therefore, the development of weakly volatile reservoirs under bubble point pressure has advantages and disadvantages. It is necessary to balance the advantages and disadvantages with practical problems.

5. CONCLUSION

In this paper, according to the physical properties of the weakly volatile reservoir, the live oil with similar dissolved gas-oil ratio was prepared, and the gas saturation was similar to the actual reservoir at the end of depletion, which made the experimental conclusion better applied to the actual reservoir. This paper designed a three-phase metering device, which can realize accurate measurement of flow rate, to obtain the variation law of GOR and water cut. Finally, the influence of depletion development degree was discussed. The above research has guiding significance for weakly volatile carbonate reservoirs.

ACKNOWLEDGEMENT

Funding: This work was supported by the National Natural Science Foundation of China (No. 52004307); the China University of Petroleum (Beijing); and the State Key Laboratory of Petroleum Resources and Prospecting.

REFERENCES

[1] Hillgartner Heiko, Paino Wan-Faisal, Hadhrami Fahad, et al. Integrated Reservoir Modeling for Water Flood Development in a Heterogeneously Fractured Carbonate Reservoir, North Oman. SPE Reservoir Characterisation and Simulation Conference and Exhibition 2011.

[2] Gladkov Pavel-Dmitrievich, Zheltikova Anastasiia-Vladimirovna. Forecasting the Water Flooding for the Production Wells of a Gas Condensate Field with a Fractured Reservoir Type. SPE Russian Petroleum Technology Conference 2021.

[3] Del Ángel Morales Juan-Gerardo, Zúñiga Javier-Ángeles, Aboites Damián-López, et al. Methodology to Determine the Remaining Oil Saturation (ROS) in the Gas Cap of a Highly Fractured Carbonate Field in the Gulf of Mexico. SPWLA 54th Annual Logging Symposium 2013.

[4] Murata Sumihiko, Tarui Tadayoshi, Takahashi Satoru. Numerical Study on Water Flooding Behavior in Single Fracture using Lattice Boltzmann Method. ISRM International Symposium - 8th Asian Rock Mechanics Symposium 2014.

[5] Volgin E-R. Peculiarities of water flooding the fractured and porous reservoirs. SPE Russian Oil and Gas Technical Conference and Exhibition 2008.

[6] Li Jiahong, Song Xinming, Tian Changbing, et al. Single Sandbody Stacking Pattern, Calcareous Barrier and Fracture of Tight Low Permeability Oil Sandstone Reservoir and their Impact on Water-flooding - A Case Study of Ansai oil field, Ordos Basin, China. SPE Reservoir Characterisation and Simulation Conference and Exhibition 2015.

[7] Qu Ming, Hou Jirui, Zhao Fenglan, et al. 3-D Visual Experiments on Fluid Flow Behavior of Water Flooding and Gas Flooding in Fractured-Vuggy Carbonate Reservoir. SPE Annual Technical Conference and Exhibition 2017.
[8] Alhuraishawy Ali-K, Imqam Abdulmohsin, Wei Mingzhen, et al. Coupling Low Salinity Water Flooding and Preformed Particle Gel to Enhance Oil Recovery for Fractured Carbonate Reservoirs. SPE Western Regional Meeting 2016.
[9] Li Junchao, Lei Zhengdong, Li Shujun, et al. Optimizing Water Flood Performance to Improve Injector Efficiency in Fractured low-Permeability Reservoirs Using Streamline Simulation. SPE Kingdom of Saudi Arabia Annual Technical Symposium and Exhibition 2016.
[10] Kuzmina Svetlana, Butula Kreso-Kurt, Nikitin Aleksei-Nikolaevich. Reservoir Pressure Depletion and Water Flooding Influencing Hydraulic Fracture Orientation in Low-Permeability Oilfields. European Formation Damage Conference 2009.
[11] Li Ying, Li Haitao, Chen Shengnan, et al. Dynamic Capillarity During the Water Flooding Process in Fractured Low Permeability Reservoirs. International Petroleum Technology Conference 2019.
[12] Makinde Ibukun, Lee W-John. Production Forecasting in Shale Volatile Oil Reservoirs Using Reservoir Simulation, Empirical and Analytical Methods. SPE/AAPG/SEG Unconventional Resources Technology Conference 2016.
[13] Makinde Ibukun, Lee W-John. Production Forecasting in Shale Volatile Oil Reservoirs. SPE/IAEE Hydrocarbon Economics and Evaluation Symposium 2016.
[14] Makinde Ibukun, Lee W-John. Statistical Approach to Forecasting Gas-Oil Ratios and Solution Gas Production from Shale Volatile Oil Reservoirs. Abu Dhabi International Petroleum Exhibition & Conference 2016.
[15] Anand Vivek, Freedman Robert. New Methods For Predicting Properties Of Live Oils From Nmr. SPWLA 50th Annual Logging Symposium 2009.
[16] O Sullivan Terence-P, Astakhov Dmitriy, Gómez A. Juan-Pablo, et al. NMR-Based Method for Estimating Live-Oil Viscosity in Heavy Oil Reservoirs with Light-Hydrocarbon Charge. SPWLA 56th Annual Logging Symposium 2015.
[17] Chen Jiansheng-Jason, Chen Songhua, Smith Edmund, et al. Determination of Gas-Oil Ratio And Live-Oil Viscosity From NMR Log Incorporating Oil-Based Mud Filtrate Invasion. SPWLA 51st Annual Logging Symposium 2010.
[18] Cardoso F-M-R, Viegas C-C-B, Fleming F-P, et al. Phase Behavior of CO2-Rich Live Oil Samples From High Pressure Reservoirs. OTC Brasil 2015.
[19] Moreno R-B, Bonet E-J, Iatchuk S, et al. Residual-Oil Saturation for a Very Long Unconsolidated Core, With Live Oil at Reservoir Conditions. SPE Latin American and Caribbean Petroleum Engineering Conference 2010.
[20] Mishra Sudhakar, Pandey Amitabh. Validation of Produced Gas Rate Modelling in an Oil Reservoir with Very High CO2 Through Matching of Live Oil Coreflood. SPE Oil and Gas India Conference and Exhibition 2019.