International Journal of Science and Research (IJSR)
ISSN (Online): 2319-7064
Impact Factor (2012): 3.358

Analysis and Calculation Method for Automatic Water Flooding Technology

Yangfan Li, Guohua Zhang

CNOOC Ltd-Shanghai, 910 Room, Offshore Tower, NO. 583 Lingling Road, Xuhui District, Shanghai, China

Abstract: ***Bounded thin oil reservoir, which is characterized by less reserves, thin thickness, and weak energy of edge or bottom water, could hardly be developed with high cost, low recovery and high risk. Bajiaoting oil field has all the characteristics of bounded thin oil reservoir, what's more, it has low permeability. As a result, it could not be developed without water injection wells, but water injection cases could not be taken in Offshore Oil Fields due to the restrictions of the producing platform. Face all the difficulties, Water Flooding, which could maintain pressure and improve recovery with low cost, was, and it is the first time that this technology applied in China offshore. In this study, related calculation methods for pressure and injection rate are applied, and the effects and simulation results of some adjustment cases are discussed.***

Keywords: Automatic, Flooding, Bounded Reservoir, EOR, Numerical Simulation

1. Introduction

Bajiaoting Oil Field is a part of East China Offshore oil fields. Conventional development started in October 2007, till now, there are two production wells: BO1 and BO2. (BO means Bajiaoting Oil). In the early period, there was a high oil production with a rapidly decrease. Afterwards, in order to maintain oil production, gas lift was applied. The oil production increased greatly, but still decreased rapidly. It is estimated that, the oil production is related with the effect of gas lift, and the decline trend of it could not be stopped by gas lift.

In order to maintain oil production and improve oil recovery, water flooding project was applied in 20 January 2009. A series of results from tests showed that the formation pressure had been built-up and water flooding became effective till 1 May 2009.

In this study, the development characteristics of Bajiaoting Oil Field, and the improvement of oil recovery by water flooding are described. Furthermore, a series of adjustment cases are discussed.

2. Design and Practice of Water Flooding

In order to stabilize oil production and improve oil recovery, water flooding plan was adopted and applied in 20 January 2009. The branch for water flooding which was named BO2-W came from well BO2 had finished drilling. BO2-W pouring water into H4B by using water layer H3.

On 2 February 2009, the gas volume of gas-lift of BO1 was cut down, afterwards, daily oil production decreased to about 25 m3/d. During that time, for the interference of the gas injection, it was still not clear whether the water flooding worked effectively or not.

On 1 May 2009, the tests of flowing pressure, static pressure gradient, static temperature gradient and pressure recovery were made on well BO1, which showed the formation pressure built up obviously, and proofed that the water flooding took effect indeed (Figure 1).

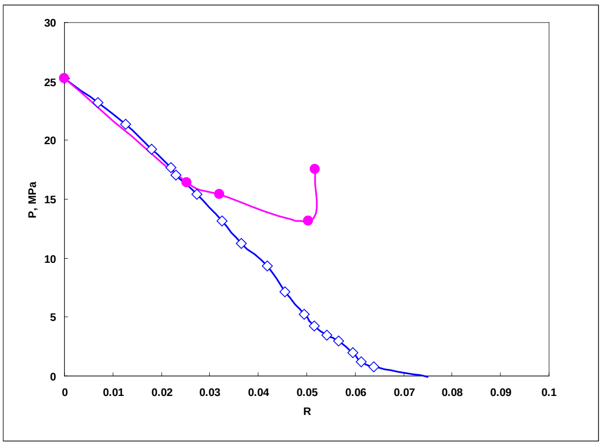

Figure 1: Effect of water flooding on maintaining pressure

3. Mathematics

The main difficulty of a flooding system is that after finishing drilling the Water-Flooding branch, the wellbore was blocked off artificially. As a result, it faced several problems:

- Flooding rate could not be controlled directly.
- Flooding rate could not be measured directly by instruments.
- Flooding rate process could not be turned off in require of measurements, as a result, static pressure could hardly be measured.

For these reasons, the pressure of the aquifer is deemed as an invariant, the pressure of the reservoir and the flooding rate could be calculated by mathematics.

Sedimentary facies indicates that the connectivity between wellblock BO1 and wellblock BO2 is weak. Water flooding could hardly affect wellblock BO2, therefore, wellblock BO1 could be considered as a closed system which only contains an oil well and a water flooding branch.

Before Water Flooding, the formula to calculate average pressure of H4B is defined as follow:

$$\overline{P} = P_i - \frac{q_o B_t}{24\phi h_4 C_t A} \quad (1)$$

Where P_i is the original pressure of reservoir, q_o is the oil production, B_t is the total volume factor, φ is the average porosity, h_4 is the average thickness of reservoir H4, C_t is the total coefficient of compressibility, A is the area of reservoir.

Initial water flooding rate could be calculated by the formula as follow:

$$q_w = \frac{P_3 - P_4 + \rho_w g h_3 / 10^6}{1/J_3 + 1/J_4} \quad (2)$$

Where P_3 is the average pressure of H3 (water layer), P_4 is the average pressure of H4 (oil layer), ρ_w is the density of water in layer H3, h_3 is the thickness of water layer, J_3 is the water production coefficient in H3, J_4 is the injectivity coefficient of water in H4.

When the water flooding started, the average pressure of H4B could be calculated by the formula as follow:

$$\overline{P} = P_i - \frac{q_o B_o - Q_{inw} B_W}{Ah\phi C_t} \quad (3)$$

Where q_o is the oil production, B_o is the oil compressibility, Q_{inw} is the cumulative water injection, B_w is the water compressibility.

The pressure in H4B could be matched by formula (1) before water flooding, and could be matched by formula (2) and formula (3) when the water flooding started. After the pressure matching work, the future pressure and water injection rate could be calculated with the oil production schedule by the formulas. The data of pressure matching is shown in Figure 2.

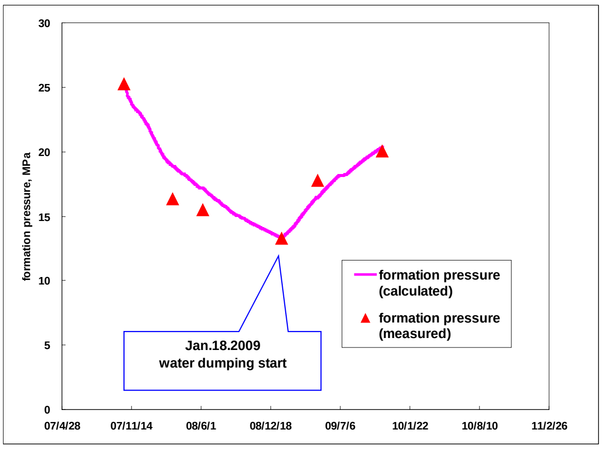

Figure 2: Pressure matching

After the matching work, the pressure could be cauculated according the varid producing plan, as shown in Figure 3.

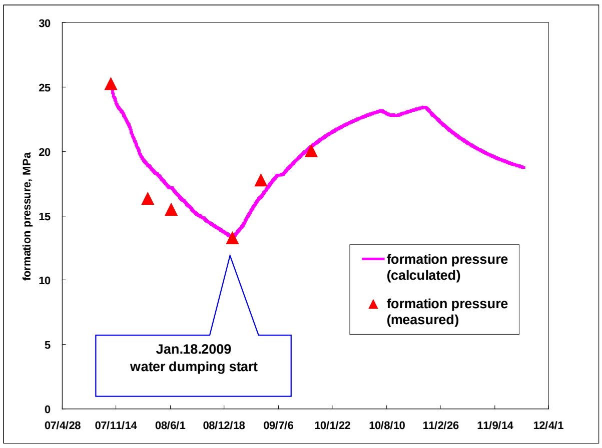

Figure 3: Pressure matching and prediction

The prediction of pressure and water injection rate shows in Figure 4. The prediction of cumulative water injection shows in Figure 5.

By using this method, in 2009, the prediction shows that the average pressure of H4B would reach about 23.1 MPa till 22 July 2010. After that, in 22 July 2010, pressure test was taken. The pressure of H4B was calculated as 22.3 MPa according to the hydrostatic gradient. It proved that the method is trustworthy.

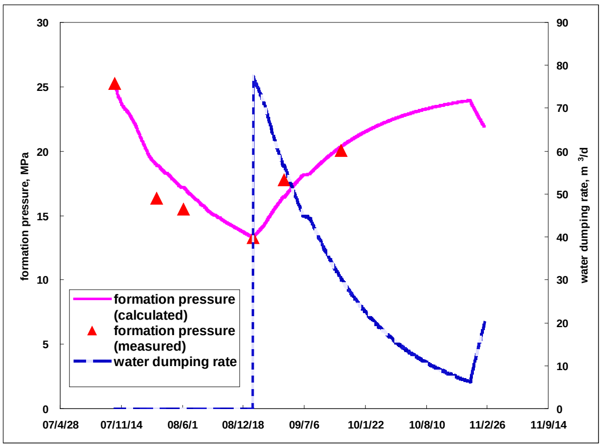

Figure 4: Prediction of pressure and water injection rate

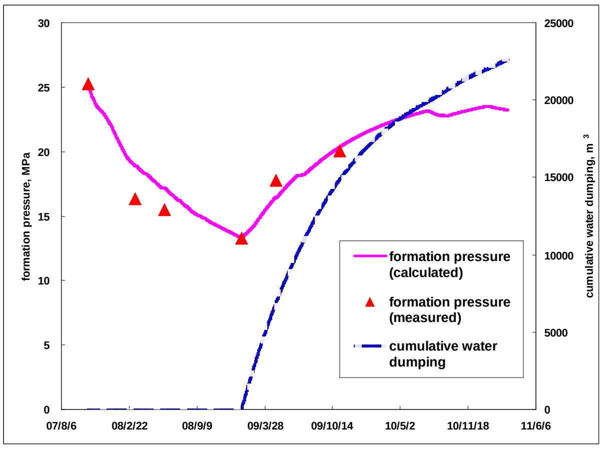

Figure 5: Prediction of pressure and cumulative water injection

4. Numerical Simulation

As the development progresses, the water flooding range will gradually expand. In this change, the effect of water flooding will be weakened, and the error which comes from the calculated result will increase gradually. The process is difficult to complete by conventional calculation method. Therefore, numerical simulation method was chosen for the next step of study. Geologic model contains water layer in the top and oil layer under it.

The pressure measurement on Well BO1 was carried out respectively on 24 October 2007, 10 March 2008, 5 June 2008, 18 January 2009, 1 May 2009, 4 November 2009, and 18 March 2011. The Figure 6 shows the case of each pressure point matched by numerical simulation method.

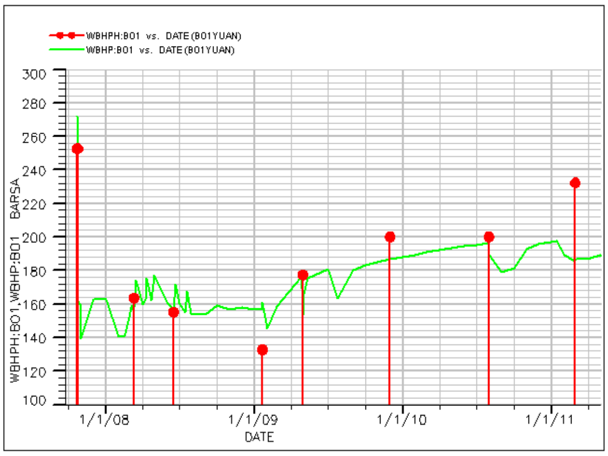

Figure 6: Pressure Mathing by Numerical Simulation

After fitting each pressure point, the changes among the corresponding formation pressure, oil production and cumulative oil production can be worked out according to the different producing plans. As shown in Figure 7.

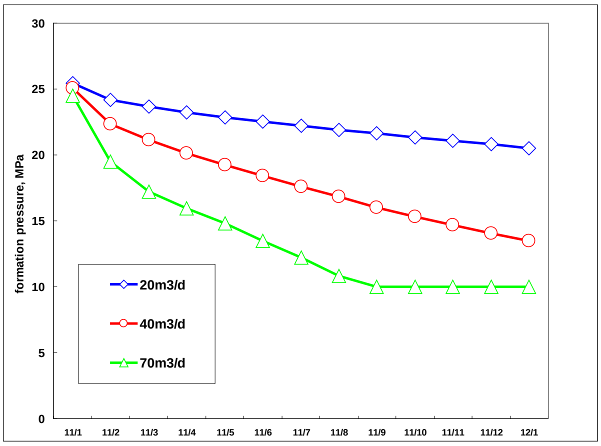

Figure 7: Prediction of pressure under different producing plans

Three producing plans: 20 m^3/d, 40 m^3/d, and 70 m^3/d, were chosen for this test. Figure 8 is the case of oil production change in different producing plans, and Figure 9 is the case of cumulative production change in different producing plans.

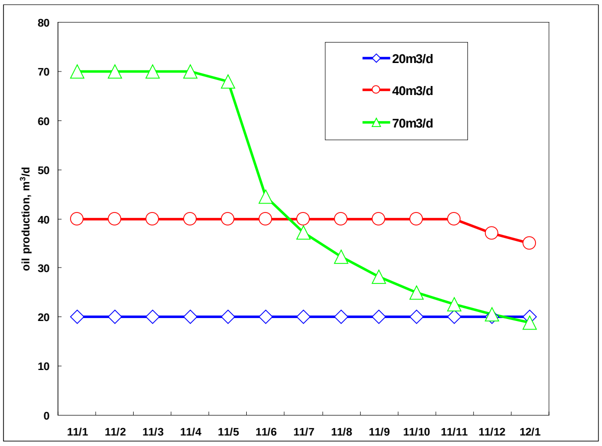

Figure 8: Prediction of oil production under different producing plans

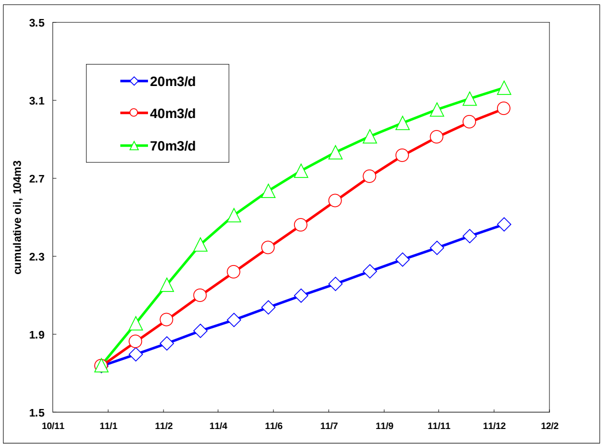

Figure 9: Prediction of cumulative oil production under different producing plans

As can be seen from the Figures, the production was difficult to stabilize after the producing planned increased. And meanwhile, as the water flooding was only carried in the western region, the oil was difficult to drive in the eastern part. For this reason, the research of the adjustment cases to keep stable production and develop remaining oil in the eastern part should be carried on.

5. Adjustment Cases

Case 1: Original Case

It means: keeping original production condition without any change or adjustments.

Case 2: Increase a production well

As the centre and the western areas of H4B were affected by water flooding, remaining oil can be gradually produced, however, the reserves in the eastern area could hardly to drive, and lots of remaining oil existed in the eastern. As a result, a horizontal well BO3 increased in the eastern area of H4B can be considered.

Case 3: Increase a water flooding well

The potential tapping result obtained after increasing a production well in the eastern part of H4B is not satisfying, so water flooding well BO3-w increased in the eastern part of H4B can be considered.

6. Results

Case 1: Original Case

Figure 10 is the distribution of remaining oil around well BO1. As can be seen from it, the water invasion is still not spread to the well BO1 at present. BO1 do not have lots of water production pressure at the moment, but the formation pressure drop quickly. According to calculations, the well BO1 will produce water after it produce oil for about a year, thus, water injection well will connect with the well BO1, afterwards, the water cut increases rapidly, which however, increase the difficulties of oil production.

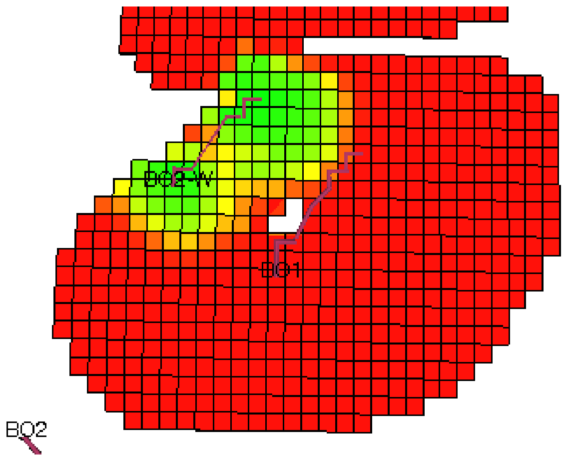

Figure 10: Distribution of remaining oil

Gas-lift was not used after water flooding, so intermittent production instead of gas-lift will be considered in this calculation, taking flowing pressure as restrictive conditions.

According to the conversion of Static pressure gradient, the wellbore loss was 18.2 Mpa. Taking the lowest flowing pressure 14 MPa as restrictive conditions, the calculation shows that the well BO1 will be depleted in 2014. The cumulative production of the well BO1 will reach 3,3000 m^3 at last based on the prediction. The present oil production is 2,2000 m^3, and the remaining production is about 1,1000 m^3. Figure 11 and Figure 12 respectively shows the oil production and the change of formation pressure, and the relation between cumulative production and formation pressure.

When the well BO1 was depleted, the water flooding of BO2-W can not reach the eastern part of BO1 in this scheme; therefore, abundant remaining oil can not be produced in the eastern part. Hence, this scheme will not be adopted.

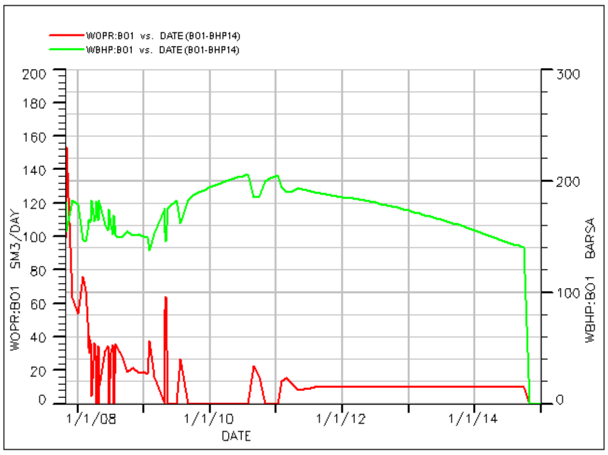

Figure 11: Prediction of oil production and pressure

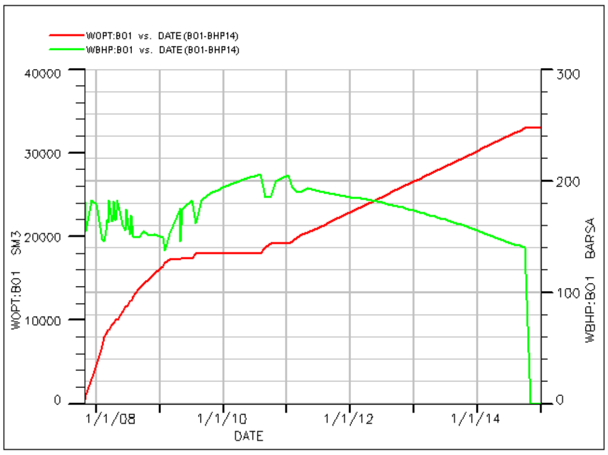

Figure 12: Prediction of cumulative oil production and pressure

Case 2: Increase a production well

A horizontal well BO3 case was designed to develop the remaining oil in the eastern part of H4B. The coverage of water flooding by BO2-W could not include the east part of H4B, therefore, the remaining oil in the eastern part can hardly be produced in current situation. As a result, this case could not be adopted.

Case 3: Increase a water flooding well

Increase a water flooding well BO3 in the eastern part of H4B. It is suggested that the well BO3 should be a horizontal well, which can be sidetrack drilled by the well BO2. Under the influence of double well water flooding, ideally, well BO1 could produce the remaining oil in the east area of H4B with the help of well BO3's water flooding, the cumulative production will be 5,4000 m^3 when it is depleted, which means that the increased production is about 2,1000 m^3.

The distribution of remaining oil can be seen in Figure 13, and the prediction of oil production and cumulative production can be seen in Figure 14.

ISSN (Online): 2319-7064
Impact Factor (2012): 3.358

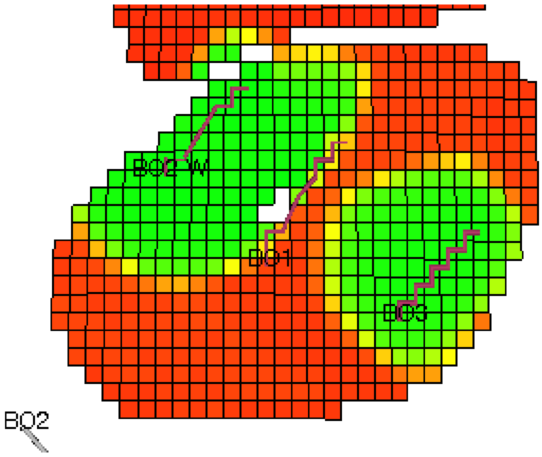

Figure 13: Distribution of remaining oil (Case 3)

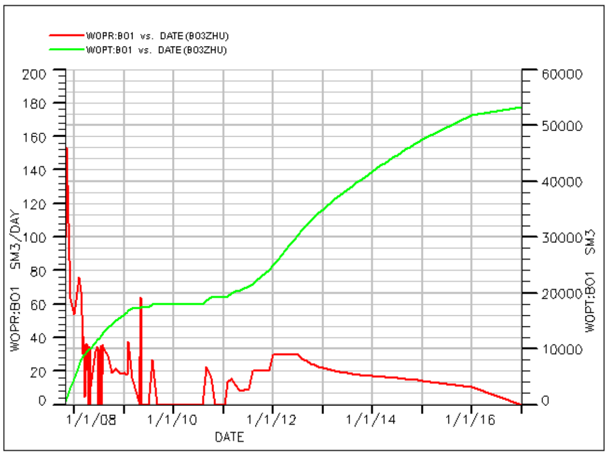

Figure 14: Prediction of oil production and cumulative oil production (Case 3)

7. Analysis

Since the Case 1 and Case 2 are inferior to the Case 3, the analysis is around Case 3, and it contains Risk and Schedule.

- **Risk analysis**

BO2-W could maintain water flooding, and then the BO2-W and BO1 may be connected with water through the high permeability zone in the future. Once connected, well BO1 and well BO2-W well will form a new pressure balance, therefore, the well BO3 could not get pressure supply, and well BO3 could not maintain production.

- **Schedule Analysis**

If the two flooding wells could finish drilling at the same time, the effect will be better. At present, due to the first flooding well has been working for three years, so the effect of using of the second flooding well will be weakened due to the unbalance between west and east.

8. Conclusions

The following conclusions could be drawn according to the results obtained in this study:

- Water Flooding is an applicable choice to develop the thin reservoir in the offshore because of its advantages: little pollution, low cost, and so on.
- Iteration method under material balance can be used to calculate the water injection, accumulative water injection. Furthermore, it could be used to predict reservoir pressure in the future under any production plan.
- After finishing drilling, the water flooding wells could not be controlled directly, and the process of the water flooding could not be shut down. Therefore, any negative effects (if occurred or will occur) could be eliminated or changed by other wells only.
- After connecting with the water flooding well through water flooding, the production well could not maintain production. Therefore, any stimulation treatment such as chemical flooding, fracturing technology, etc., should be taken place before the water flooding project.

Nomenclature

P_i = original pressure, MPa
q_o = oil production, m^3/d
φ = porosity
B_t = total volume factor
B_o = oil compressibility
B_w = water compressibility
Q_{inw} = cumulative water injection, m^3
ρ_w = density of water, kg/m^3
A = reservoir area, m^2
B_t = volume factor total
C_t = Coefficient of Compressibility total
h_3 = thickness of water, m
h_4 = thickness of reservoir, m
P_3 = average pressure of H3, MPa
P_4 = average pressure of H4, MPa
J_3 = water production coefficient in H3
J_4 = injectivity coefficient of water in H4

References

[1] Kazuo Fujita. Pressure Maintenance by Formation Water Flooding for the Ratawi Limestone Oil Reservoir, Offshore Khafji. SPE 9584 first presented at the 1981 SPE Middle East Oil Technical Conference and Exhibition in Baharain, March 9-12. Journal of Petroleum Technology. Volume34 Number 4. Pages 738-754.
[2] Wafa Shizawi, Hamed Subhi, Ahmed Rashidi, Arunangshu Dey, Fathiya Salmi, Mohammed Aisary. Enhancement of Oil Recovery through Flooding-flood Water injection concept in Satellite Field. SPE 142361, SPE Middle East Oil and Gas show and conference held in Manama, Bahrain, 25-28 September 2011.
[3] Mamdouh M Ibrahim, James W Style, Hesham L Shamma, Mamdouth A Elsherif, Essam M Abo Elalla. Environmentally Friendly and Economic Waterflood System for October Field at Gulf of Suez, Egypt. SPE Indian Oil and Gas Technical Conference and Exhibition, 4-6 March 2008, Mumbai, India.
[4] S. A. Ghonie. Variable Salinitu Aquifer and Its Effect on Reservoir Performance. SPE 15715, prepared for presentation at the Fifth SPE Middle East Oil Show held in Manama. Bahrain, March 7-10, 1987.
[5] Edward E. Johanson. Predicting Dredge Material Dispersion in Open Water Flooding as a Function of the

Material Physical Characteristics. SPE 2589, Offshore Technology Conference, 3-6 May, Houston, Texas.

[6] S. Lomovskikh, V. Smyslov, E.Sukhov, V. Shashel, SPE, V. Kozhin, Y. Nekipelov. Optimization of produced water flooding using conceptual model of field infrastructure. SPE 138078, SPE Russian Oil and Gas Conference and Exhibition, 26-28 October 2010, Moscow, Russia.

Author Profile

Yangfan Li received the Master degree in Yangtze University (China). He is currently a petroleum engineer in CNOOC (China National Offshore Oil Company). His research interests include energy, petroleum, fluid mechanics, etc.