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.

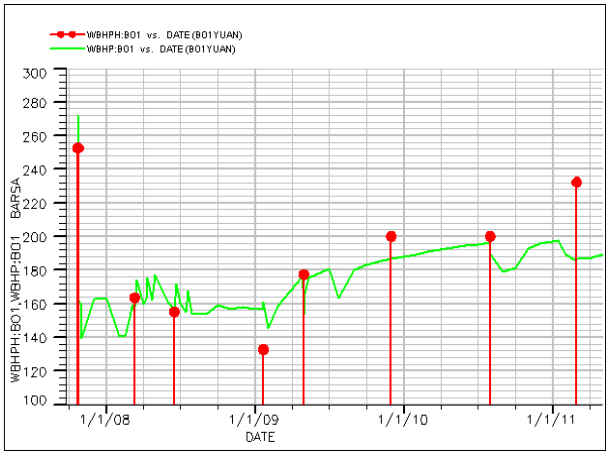

Figure 6: Pressure Mathing by Numerical Simulation

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.

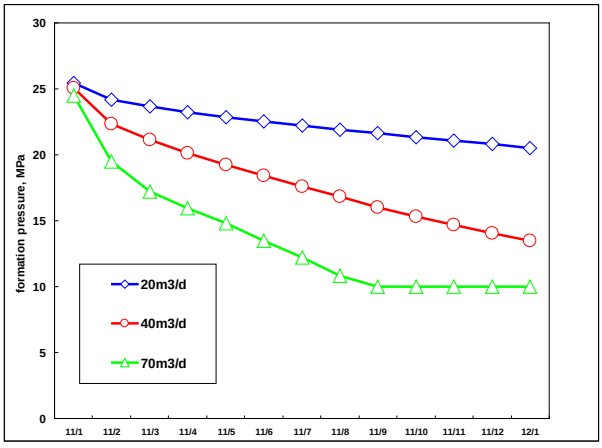

Figure 7: Prediction of pressure under different producing plans

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.

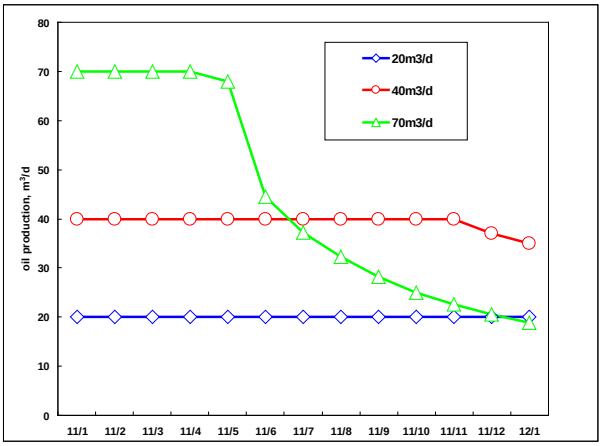

Figure 8: Prediction of oil production under different producing plans

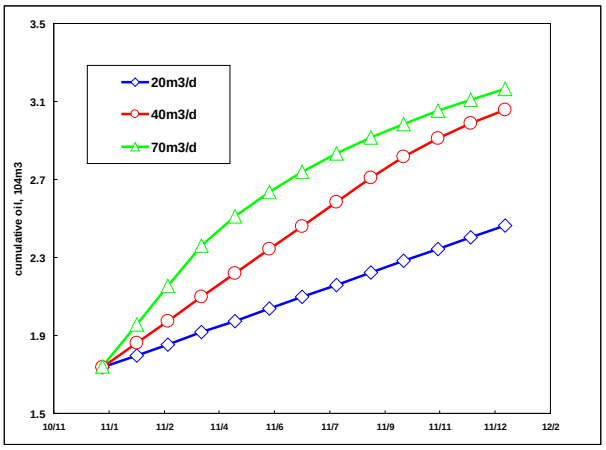

Figure 9: Prediction of cumulative oil production under different producing plans

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.

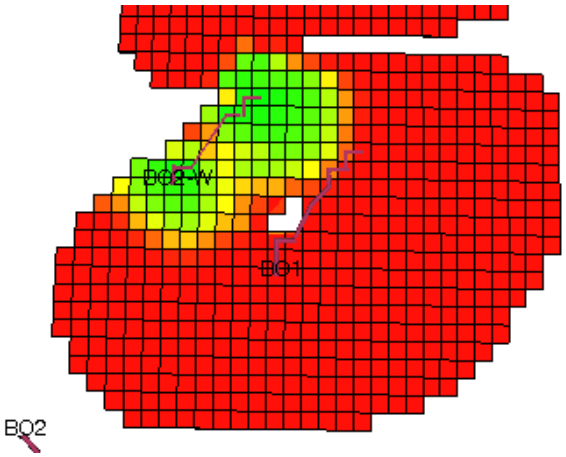

Figure 10: Distribution of remaining oil

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.

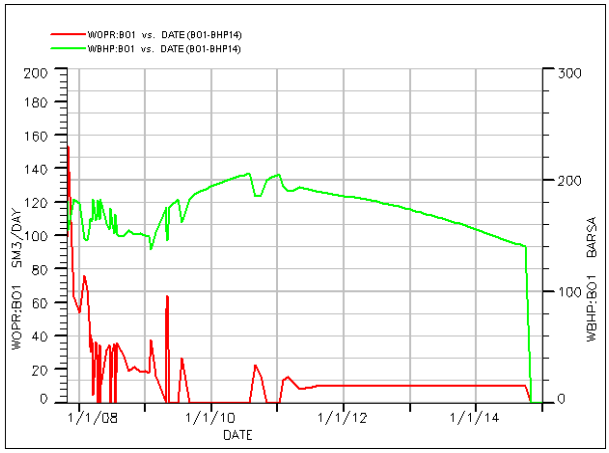

Figure 11: Prediction of oil production and pressure

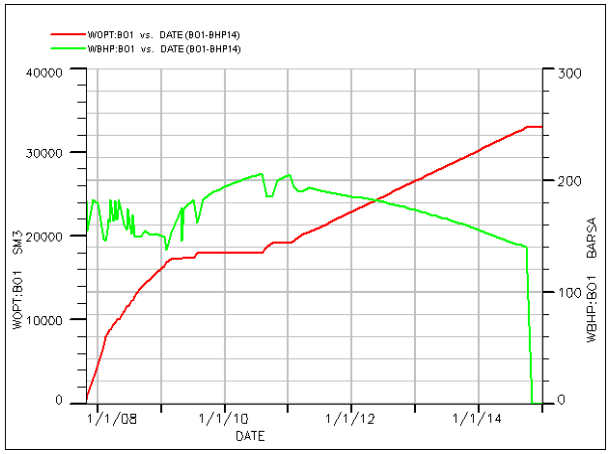

Figure 12: Prediction of cumulative oil production and pressure

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.

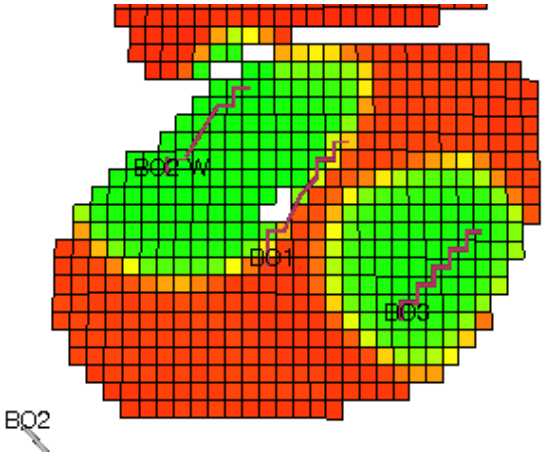

Figure 13: Distribution of remaining oil (Case 3)

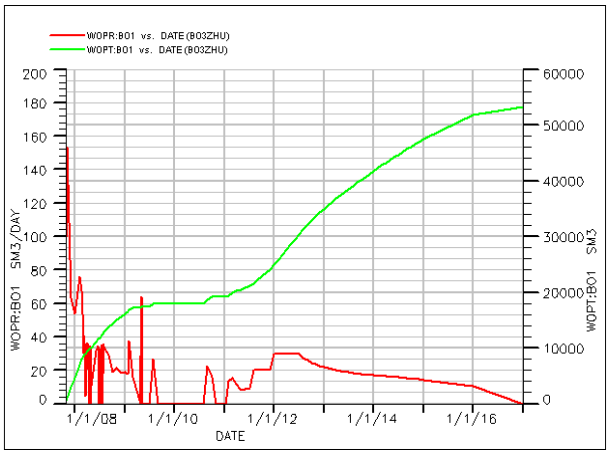

Figure 14: Prediction of oil production and cumulative oil production (Case 3)

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

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