Nitrogen Foam Profile Control Improves Steam Huff and Puff Development Effect

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Abstract. After the XQ-45 block entering the multiple rounds of steam huff and puff, it is affected by faults, reservoir properties, edge water and other factors. The remaining oil distribution is complex, and steam huff and puff effect is getting worse. According to the reservoir dynamic data, this block is selected as a test block to improve the steam huff and puff development effect of nitrogen foam. The 79 wells in this block are divided into different types of heavy oil wells according to the remaining oil saturation parameters. Aiming at the high-level intervals in the oil wells with different layers, then take nitrogen foam profile control measures to adjust the suction profile, and optimize the optimal nitrogen foam injection parameters are: nitrogen foam injection volume is 0.2pv, foam concentration is 0.5%, gas liquid ratio is 2: 1, cycle steam injection volume is 100t/m. The results show that the oil production is the largest in the second round of profile control, the average daily oil production is 3.89t, and the cycle oil-gas ratio reaches 0.32. On this basis, continue to increase the profile control round, after the profile control 5 rounds, the average daily oil production is 3.18t, the average oil-gas ratio is 0.26, the cycle of cumulative oil production is 1431.23t, and the program implementation effect is getting better.

1 INTRODUCTION

At home and abroad the application of foam fluid has nearly 30 years of history in oil field. The composition form of foam fluid is also evolved from single ordinary foam flooding to current compound nitrogen foam flooding (Zhao et al., 2009; Yang, 2014; Huseyin, 2013). After the 80's, domestic oil field has made a major breakthrough in the application of foam fluid technology. The foam is gradually recognized as main mechanism to improve recovery ratio of heavy oil after entering multiple rounds of steam huff and puff (Zhang et al., 2012; Li et al., 2007; Tian, 2015), it has conducted the relevant indoor and field study in the field.

Zhang Liehui etc have proposed foam flooding empirical model. Compared with other models, the model except adds a surface active agent flowing equation, the model does not require any additional large amounts of data. This feature makes this model widely used in the software customization (Zhang et al., 2000; Fan et al., 2009; Rossen and Zhou 1994); Liao Guangzhi, Chen Guo etc have established a mathematical model to describe polymer alkali active agent and foam fluid combination flooding (Chen et al., 2001; Zhang et al., 2012; Malcolm, 2004). Aimed at the second north block in Shengli oil field, and launched a pilot test to improve recovery ratio of injecting nitrogen foam. It is found that technology of nitrogen foam can effectively supplement layer capability in this block and improve swept volume (Zhou et al., 2006; Cao et al., 2013; Cao et al., 2006). With the effect of weak gel profile control rapid decline, liaohe oil field has established laboratory test of nitrogen foam profile control. According to laboratory findings, confirmed a series of field nitrogen foam injection scheme. It is demonstrated that inject nitrogen foam can effectively plugging tall permeation high capacity channel of oil layer, enhance swept volume, and improve effect of water injection (Yang et al., 2004; Islam et al., 1989). Aimed at the needs of Daqing

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Sabei oil field development, and launched pilot test of nitrogen foam flooding in the Beiding well and xing well. It is confirmed that availability of nitrogen foam flooding in the field is good, and foam combination flooding can improve oil recovery 30% than water flooding (Zhang et al., 2001; Wang and Zhang, 2007; Islam, 1989).

After XQ-45 block entering the high cycle of steam huff and puff, distribution of remaining oil is complex, and the effect of steam huff and puff is getting worse. Due to the heterogeneity of reservoir layers, steam overlapping and steam enthalpy occur, which leads to steam escaping along the high permeability zone, making the steam sweep efficiency small, greatly reducing the effective steam sweep area and affecting the efficiency of steam huff and puff. Aiming at this issue, in order to further study the effect of nitrogen foam profile to improve the development of steam huff and puff, the block wells are divided into five types of remaining heavy oil wells, potential of these five remaining oil wells is analyzed and nitrogen profile study of the most potential inter-layer differential wells is conducted. Parameters of optimal nitrogen foam injection are optimized, and effect of nitrogen foam profile control inter-layer differential wells development is confirmed.

2 BLOCK OVERVIEW

2.1 Reservoir Geological Features

XQ-45 block is located in the north east direction of the Xinzhuang complex fault block in the northern slope of the Biyang depression. This part of strata is mainly composed of three different oil groups and unconformity contact of angle in the third system.

The whole area contains oil-bearing horizon group Ⅱ. The main oil layers are H3Ⅱ2 oil layer, H3Ⅱ3 oil layer, H3Ⅱ5 oil layer and H3Ⅱ6 oil layer, and effective thickness of oil layer is 0.8-10.4 meters. Buried depth of reservoir is 75 ~ 245m, the average of oil layer assemble thickness is 8.2m, and the pure gross thickness ratio is 0.5-0.99. Reservoir lithology mainly consists of linen rudstone, glutenite and siltstone. Cementing materials are dominated by earthy material. Type of cementation is generally as pore cement. Oil reservoir has better physical properties with average porosity of 30.44% and mean permeability of $2209.4\times10^{-3}\mu m^2$. Relative density of ground crude oil between 0.9361 cm^3 and 0.9666g/cm^3, content of gummy asphalt is 6.3%～33.43%, paraffin content is 2.87%～9.06%, sulfur content is 0.03%～0.12%, solidifying point is -2℃～7℃, viscosity of degassed crude oil is 11258～20876mPa·s, which belongs to particularly heavy oil reservoir.

2.2 Steam Huff and Puff Development Process

XQ-45 block has been put into large scale development since 2005. After five years of steam huff and puff, by the end of April 2011, a total of 76 oil wells have been put into production, with cumulative liquid production is 110.23×10^4t, combined water content is 85.7% and cumulative oil-gas ratio is 0.23.

Since June 20, 2011, due to infancy of steam flooding is not effective and oil-gas ratio is poor. XQ-45 block implements injection and production parameters adjustment, nitrogen foam assists steam flooding and other measures, it is found that steam flooding production wells gradually effective, daily oil production and oil-gas ratio increase year by year. By the end of December 2015, a total of 72 oil wells have been devoted to development and 58 wells as open wells. The average single well throughput is 10 cycles, daily fluid production is 523.6t, daily oil production is 32.1t, and water content is 93.9%. Cumulative oil production is 22.7049×10^4t, degree of reserve recovery of producing reserves is 23.3%, cumulative steam injection volume is 94.6038×10^4t, and cumulative oil-gas ratio is 0.24.

2.3 The Main Problems in the Development Process

With increase of the number of throughput cycles, development effect of the block gradually deteriorated. At present, the average steam huff and puff cycle has reached more than 10 cycles and the average of degree of reserve recovery is about 18.6%. The average single-well daily production is only 0.6t and oil-gas ratio is about 0.13. After the development of high cycle throughput and steam flooding, following problems mainly restraint the effect of development and the increase of recovery ratio: (1) Section plane heterogeneity is strong, and degree of utilization is disproportionation. (2) After high cycle of steam huff and puff, pressure is low, and daily liquid production of single well is low. Oil-gas ratio is low and the effect of development is poor. There are many low production wells and invalid production wells. In the XQ-45 zone, the average steam cycle has reached 10 cycles, the formation pressure has dropped to 0.8MPa-1.2 MPa, and the pressure maintenance level is only about 40%.At present, the average daily production of single well is 9t, daily oil production is 0.6t , water content is 93.3%, oil-gas ratio is 0.13, which has poor development. Among them, there are 10 normal production wells with daily production of more than 1.0t and 49 low-efficiency wells with daily production of less than 1.0t. (3) Remaining oil distribution is complex, and the realization of tapping potential is difficult. The remaining oil recognition method is only the logging interpretation method and the reservoir engineering method, and it is limited to single well points and small layers. The remaining oil potential is difficult to recognize and evaluate, and it restricts the fine adjustment and potential tapping of the reservoir in the later period.

3 CLASSIFICATION AND POTENTIAL ANALYSIS OF REMAINING OIL TYPES IN HEAVY OIL WELL

3.1 Remaining Oil Classification of Five Heavy Oil Wells

Combining actual production data of liquid producing capacity, gas injection volume and water content of each well, and based on the data of geologic analysis and well logging interpretation. According to different parameters such as remaining oil saturation and degree of reserve recovery, 79 wells in XQ-45 block are measured to establish the classification criteria.

There is edge water in the small layers of block, and area of edge water block is unequal. With the continuous of the process of pressure releasing and producing, edge water along the high permeability zone with better physical property advances into the well. At this time, oil productive capacity rapid decline, water production rapid increase. As a result, layers around oil wells are not evenly used, and they are identified as oil wells affected by edge water.

The block is mainly controlled by faults, and the radius of oil drainage is significantly affected by faults. The value of remaining oil saturation nears the fault is relatively high, and degree of reserve recovery is relatively low. So that, oil wells in this block are confirmed fault screened heavy oil wells.

The criteria for dividing inter-layer differential type of remaining oil is: the value of average remaining oil saturation difference between H3II2, H3II3, H3II5 and H3II6 four layers are≥0.12.

The criteria for dividing intra-layer differential type of remaining oil is: the value of remaining oil saturation difference in the three small layers of H3II31, H3II32 and H3II33 are≥0.08.

According to the distribution of the remaining oil saturation field, except for the types of remaining oil wells above, which the remaining oil wells are still rich at the end of the recovery, are divided into the interwell enrichment remaining oil wells.

On the basis of the results of the five types of remaining oil, the single well controlled geological reserves are calculated according to the volumetric method, and the degree of reserve recovery of the five type of remaining oil type wells are analyzed. The average degree of reserve recovery of interwell enrichment wells is 22.9%, the average degree of reserve recovery of intra-layer differential remaining oil wells is 28.1%, the average degree of reserve recovery of inter-layer differential remaining oil wells is 24.5%, the average degree of reserve recovery of edge water affected wells is 21.7%, and the average degree of reserve recovery of fault screened oil wells is 8.23%.

3.2 Potential Analysis of Five Type Remaining Oil Wells

According to the degree of reserve recovery of the five type remaining oil wells, the remaining oil potential classification evaluation is performed. The remaining oil potential evaluation criteria are: the oil wells with less than 10% degree of reserve recovery have the high potential of remaining oil, the oil wells with degree of reserve recovery of 10%-25% have the medium potential of remaining oil, the oil wells with more than 25% degree of reserve recovery have the low potential of remaining oil. It is concluded that the order of the production of five types of heavy oil wells is as follows: intra-layer differential type ＞ inter-layer differential type ＞ interwell enrichment type＞ edge water effected type＞fault screened type.

According to the evaluation criteria for remaining oil potential, the remaining geological reserves of the five remaining oil types are calculated. The order from high to low is as follows: inter-layer differential type＞ edge water effected type＞ fault screened type＞ interwell enrichment type＞ intra-layer differential type.

According to the above analysis, the remaining oil potential of the five heavy oil wells is as follows: inter-layer differential type＞ edge water effected type＞ fault screened type＞ interwell enrichment type＞ intra-layer differential type. It is can be seen that the inter-layer differential type remaining oil is the high potential of the remaining oil in the five heavy oil wells, so the analysis its causes.

3.3 Analysis the Development of Inter-Layer Differential Type Remaining Oil Wells

The formation and distribution of inter-layer differential type remaining oil are mainly affected by interlayer barrier, inter-layer heterogeneity and perforation interval. The virgin formation oil layers in the same wells generally maintain characteristics of the native reservoir, and a high remaining oil distribution in the local zone is formed. The temperature loss of barrier limits the effective range of steam flooding, so that more remaining oil is formed in the upper part of barrier to form a high remaining oil enrichment zone. The inter-layer thermal interference makes high permeability layers communication transform to form steam communication, so that the relatively low permeability layer or disconnected layer form high remaining oil.

4200 well in the block is selected to analysis. For H3II3 layer, the value of porosity is 32.96%, the value of permeability is $1660\times10^{-3}\mu m^2$, and the value of remaining oil saturation is 0.41. For H3II5 layer, the value of porosity is 39%, the value of permeability is $479\times10^{-3}\mu m^2$, and the value of remaining oil saturation is 0.54. For the two layers mentioned above, the difference value of permeability is $1181\times10^{-3}\mu m^2$, and the difference value of remaining oil saturation is 0.13. Conflicts between layers is large, thus inter-layer differential type of remaining oil is formed.

4 STUDY ON NITROGEN FOAM PROFILE CONTROL INTER-LAYER DIFFERENTIAL TYPE OIL WELLS

According to the inter-layer differential type remaining oil wells, on the basis of actual production data such as the potential productivity of single-layer remaining oil, the effective thickness of oil layer, the cumulative oil production and the degree of reserve recovery. The representative 4003 well and 4502 well are selected to optimize design.

Due to the difference heterogeneity of reservoir layers, steam overlapping and gas channeling occur. It is results that the steam rushes into the high permeability zone, makes sweep efficiency of steam small and greatly reduces the effective area of steam, thus affects the efficiency of steam huff and puff. Aiming at the high degree of reserve recovery of layer in inter-layer differential type oil wells, the nitrogen foam profile control measures are adopted to adjust the gas injection profile and mode of two layers commingled production. The nitrogen foam profile control parameters and steam injection parameters are optimized, including nitrogen foam injection volume, gas fluid ratio (nitrogen: foam liquor), foam concentration and cycle steam injection volume. Using the numerical simulation method and combining with the economic benefit analysis under the current low oil price, the best solution is obtained by obtaining the maximum crude output and the economic limit oil gas ratio greater than 0.2 as the evaluation standard.

4.1 Geological Modeling

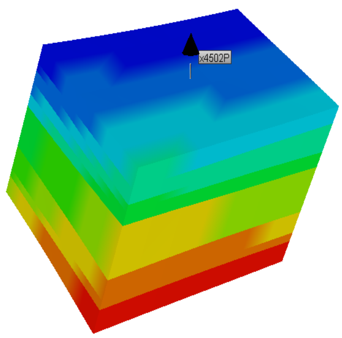

Figure 1: The geological model of 4502 well.

From the actual geological model in XQ-45 block, a single-well geological model of the new 4502 well is extracted (Figure 1). According to the single well reserves control range, the model plane size take half the well spacing is delineated (40m).

The oil production of each small layer of well 4502 is calculated, and the volume method is used to separately calculate the single wells geological reserves. The utilization of reserves in each layer is analyzed, the results show that H3Ⅱ5 layer and H3Ⅱ6 layer are imperforate into production, and the single layers of H3Ⅱ2 layer and H3Ⅱ3 layer have higher degree of reserve recovery of 71.08% and 76.73%. The total degree of reserve recovery of two layers is 74.35%. Since the cycles of steam huff and puff of H3Ⅱ2 layer and H3Ⅱ3 layer in Well 4502 have reached more than ten cycles, and on June 20, 2011, it turns to steam flooding, they are currently in a state of high water cut stage well shutdown. The average temperature of H3Ⅱ2 layer is 50.3℃. The average temperature of H3Ⅱ3 layer is 51.45℃. The temperature of oil layer is higher, the nitrogen foam profile the higher degree of reserve recovery of H3Ⅱ2 layer, H3Ⅱ3 layer is took at first, and then two layers of steam huff and puff production method is combined , in this way the volume of nitrogen foam and steam is optimized.

4.2 Nitrogen Foam Profile Control Experiment Design

In the study, there are many programs parameters design, if we conduct a comprehensive test, the test scale is very large and difficult to implement, so we can take orthogonal test method for multi-factor test, using part of the test to replace the full test, through the analysis of some of the test results, thus we can find the test rules.

The optimization program of nitrogen foams includes that the gas liquid ratio, foam concentration, the total amount of nitrogen foam injection and the steam injection. The gas liquid ratio of the four levels of 1:1, 2:1, 3:1 and 4:1 was selected, the concentration of foam was 0.3%, 0.4%, 0.5% and 0.6%.The injection volume of being selected four levels of nitrogen foam is 0.1PV, 0.15PV, 0.2PV and 0.25PV, the steam injection quantity of being selected at four levels of 80t/m, 100t /m, 120t/m and 140t/m, carrring out the orthogonal experiment design of four factors and four levels L16 (4^4), the pore volume is calculated according to the profile control radius of 30m. The porosity volume is calculated through each small layers and the effective thickness, according to the profile volume multiplier to calculate the layered profile volume, to further determine the specific parameters of profile control (Table 1).

Table 1: L16(4^4) The optimization parameter table of orthogonal experiment.

Level	factors			
	A Input	B Gas/liquid ratio	C Cycle steam injection volume t/m	D Foam concentration %
1	0.1PV	1:1	80	0.3
2	0.15 PV	2:1	100	0.4
3	0.2 PV	3:1	120	0.5
4	0.25 PV	4:1	140	0.6

According to the four factors and the four levels L16 (4^4) to design nitrogen foam profile test, a total of programs are 16.Using CMG thermal numerical simulation software to simulation and calculation the program, there are two ways to simulate foam flooding in CMG's STARS thermal simulator; the one is a semi-empirical approach, which simply reflects the foam's presence by modifying the relative permeability of the gas phase. The other is the mechanism method, the use of total balance model to simulate the formation of foam、burst、merger 、 transport and other mechanisms. This method uses the liquid film as a component of the gas phase, its concentration determines the flow characteristics of the gas phase, the form of the total balance model is similar to the material conservation equation, it divides the unobstructed foam by the density of the flowing bubbles and the density of stationary bubbles [the number of bubbles per unit volume], and affects the apparent viscosity of the foam by the density of the bubble, considers the influence of foam on the relative permeability of gas phase and the apparent viscosity. The static foam liquid film prevents the pore throats of flowing of gas; the characteristics of flowing foam are controlled by such mechanisms as foam rheology, foam formation, trapping, and merging.

The total balance model: amount of bubble increase = influx - outflow + net increase of bubble + source and sink items.

$$\frac{\partial}{\partial t}\left[\phi s_g x_f n_f + \phi s_g (1 - x_f) n_f\right] = \nabla\left[\frac{k k_{rg}}{\mu_g}\left(\nabla p_g - \frac{\rho_g M_g g \nabla Z}{144 g_c}\right)\right] + n_f q_g + x_f \phi s_g (G_f - C_f) \quad (1)$$

Table 2: Results table of orthogonal experiment.

Scheme	Group of horizontal	PV	Gas/liquid ratio	Cycle steam injection volume t/m	Foam concentrate-ion %	Cumulative oil production t
1	A1B1C1D1	0.1	1:1	80	0.3	593.27
2	A1B2C2D2	0.1	2:1	100	0.4	1035.78
3	A1B3C3D3	0.1	3:1	120	0.5	1270.65
4	A1B4C4D4	0.1	4:1	140	0.6	1362.08
5	A2B1C2D3	0.15	1:1	100	0.5	1356.51
6	A2B2C1D4	0.15	2:1	80	0.6	1343.37
7	A2B3C4D1	0.15	3:1	140	0.3	1104.77
8	A2B4C3D2	0.15	4:1	120	0.4	1067.93
9	A3B1C3D4	0.2	1:1	120	0.6	1422.73
10	A3B2C4D3	0.2	2:1	140	0.5	1414.77
11	A3B3C1D2	0.2	3:1	80	0.4	1283.16
12	A3B4C2D1	0.2	4:1	100	0.3	1097.98
13	A4B1C4D2	0.25	1:1	140	0.4	1409.77
14	A4B2C3D1	0.25	2:1	120	0.3	1418.99
15	A4B3C2D4	0.25	3:1	100	0.6	1302.68
16	A4B4C1D3	0.25	4:1	80	0.5	1221.82

n_f is the average density of flow bubbles. n_s is the average density of still bubbles. x_f is the fractional flow of flow gas. x_s is the fractional flow of captation gas. G_f is the bubble production speed. q_g is the gas injection or output rate. Φ is the porosity. s_g is the gas saturation. u_g is the Darcy flow velocity.

The total balance model is a more comprehensive description of the various mechanisms in the process of foam seepage, with high accuracy. In this study, the mechanism model was used to simulate the orthogonal experimental scheme and the following experimental results were obtained (Table 2).

It can be seen from figure 2. With the nitrogen foam volume increasing, the cumulative oil production increasing, and the economic cost of nitrogen foam also continue to increase. When the nitrogen foam volume is 0.2PV, the trend of cumulative oil production tends to be flat. When nitrogen foam volume continued to increase to 0.25PV, the increase of cumulative oil production is relatively small, so that determines the optimal nitrogen foam injection is 0.2PV.

It can be seen from figure 3. With the continuous increase of the gas liquid ratio, the cumulative oil production increases first and then decreases. When the gas liquid ratio is small, the amount of foam produced is less and the foam system is unstable, which does not fully display the function of profile control. When the gas liquid ratio is 2: 1, the foam plugging drive and the function of nitrogen to help discharge are best. When continue to increase the proportion of gas liquid ratio, due to poor stability of the thin foam liquid film, and large doses of nitrogen easily lead to steam channeling. It is resulted that oil production is low and the effect of degree of reserve recovery is poor. So that determines the best gas liquid ratio is 2: 1.

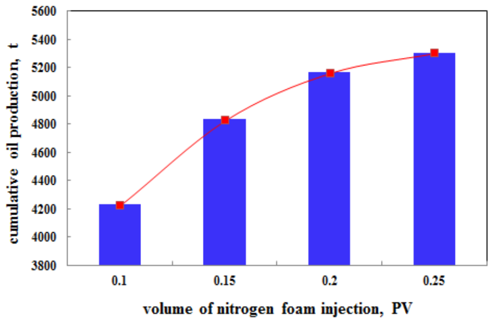

Figure 2: Effect curve of nitrogen foam injection on cumulative oil production.

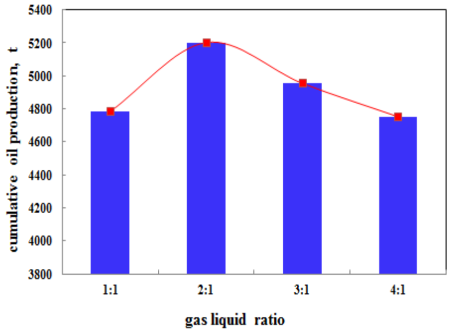

Figure 3: Effect curve of nitrogen foam gas liquid ratio on cumulative oil production.

Table 3: Optimal case table of 4502 well nitrogen foam profile control.

Layer	Effective thickness	Pore volume m³	0.2PV	Bubble underground volume(m³)	N2 underground volume m³	Foam concentrati on t	N2 above ground volume m³
H3 II 2	4.4	4251.32	850.26	283.42	566.84	1.42	33273.51
H3 II 3	6.6	5822.01	1164.40	388.13	776.27	1.94	45567.05
Total	11	10073.33	2014.66	671.55	1343.11	3.36	78840.56

Table 4: The statistics table of nitrogen foam profile control measures effect.

Cycle	Cycle oil production (t)	Cycle steam injection volume(t)	Average daily oil production (t)	Cycle oil-gas ratio
1	242.88	1100	2.70	0.22
2	350.49	1100	3.89	0.32
3	313.58	1100	3.48	0.29
4	273.79	1100	3.04	0.25
5	250.50	1100	2.78	0.23
total	1431.23	5500	3.18	0.26

According to the curve between cumulative oil production and nitrogen foam concentration (Figure 4), with the increase of the concentration, the cumulative oil production increases. When the foam concentration is greater than 0.5%, with the foam concentration continues to increase, the increase of the cumulative oil production slowed down. As the foaming agent advances in the strata, the foam system of the adsorption loss on the rock surface is occurred, and the liquid film damaged in the process of profile controlling and oil driving. The stability of the low-concentration foam system is poor, the disintegrate speed of liquid film is rapidly, and the profile controlling and oil driving effect of low-concentration foaming agent is poor. With the foam concentration continues to increase, the stability of the foam system continues to increase. When the foam concentration reaches 0.5%, the formation of liquid film has been stable enough. On the basis of continuing to increase the foam concentration, the increase of oil production is not obviously.

Therefore, the optimum concentration value of foaming agent is 0.5%.

It can be seen from figure 5. We can find that in the case of nitrogen foam profile control measures, when the cycle steam injection volume is between 80t/m-100t/m, the economic limit oil-gas ratio is in the range of 0.25-0.22. The cycle steam injection volume is above 120t/m, the economic limit oil-gas ratio is less than 0.2. Therefore, when the cycle steam injection volume is 100t/m, the economic limit oil-gas ratio can be maintained above 0.2 and the maximum oil production can be obtained at the same time. So, the cycle steam injection volume of 100t/m is optimized.

In summary analysis, the optimum nitrogen foam injection parameters are as follows: nitrogen foam injection volume is 0.2pv, foam concentration is 0.5%, gas-liquid ratio is 2: 1, and cycle steam injection volume is 100t/m.

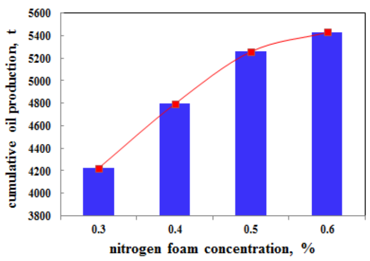

Figure 4: Effect curve of nitrogen foam under concentration on cumulative oil production.

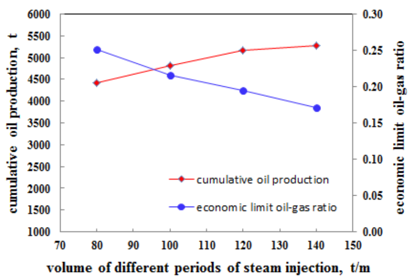

Figure 5: Different periods of gas injection cumulative oil production, economic vapor ratio curve.

4.3 Development Effect of Nitrogen Foam Profile Control

According to the optimized optimal nitrogen foam injection parameters, the nitrogen subsurface usage is converted to ground consumption according to the Clapeyron equation. The calibration equations are:

$$P_1 V_1 = n Z R T_1 \quad (2)$$

$$P_2 V_2 = n Z R T_2 \quad (3)$$

According to the 40°C wellhead temperature, the surface atmospheric pressure of 0.1MPa, the subsurface temperature of 100°C, the subsurface pressure of 7MPa and other data turn to calculation. That is, the amount of ground nitrogen is equal to 58.7 of the amount of underground nitrogen.(Table 3)

It can be seen from table 4. The oil production peak of 4502 well was 4.8t in the second rounds, and after that the daily oil production gradually decreased with the increase of the profile control round.

According to the curve of oil saturation variation and curve of temperature variation(Figure 6-Figure 7), we can find that after 5 rounds of profile control, the oil saturation value of H3 II 2 oil layers decreases from 0.43 to 0.37. The oil saturation value of H3 II 3 oil layers decreases from 0.45 to 0.35. The average temperature of H3 II 2 oil layers increases from 50.3°C to 60.38°C. The average temperature of H3 II 3 oil layers increases from 51.45°Cto 78.41°C. It is shows that the production measures of nitrogen foam effectively play the role of profile control and oil displacement. Meanwhile the production measures make the steam fully heat the oil layer to achieve the ideal sweeping effect.

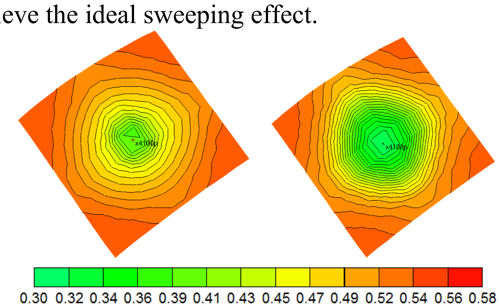

Figure 6: The remaining oil saturation field before or after profile control.

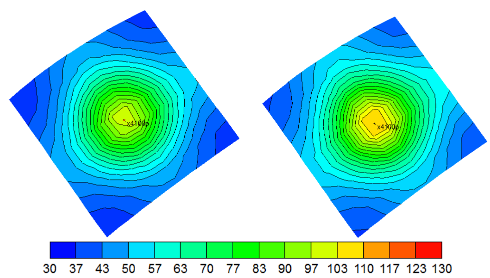

Figure 7: The temperature field before or after profile control.

5 CONCLUSIONS

The actual production data of liquid producing capacity, gas injection volume and water content of each well are combined. Based on the data of geological analysis and logging interpretation, 79 wells in XQ-45 block are measured according to the different parameters such as the remaining oil saturation and the degree of reserve recovery establishes the five types remaining oil classification criteria.

Based on the degree of reserve recovery of the five type remaining oil wells, the remaining oil potential evaluation criteria are: the oil wells with less than 10% degree of reserve recovery have the high potential of remaining oil, the oil wells with degree of reserve recovery of 10%-25% have the medium potential of remaining oil, the oil wells with more than 25% degree of reserve recovery have the low potential of remaining oil. It is concluded that the remaining oil potential of the five heavy oil wells is as follows: inter-layer differential type＞ edge water effected type＞ fault screened type＞ interwell enrichment type＞ intra-layer differential type.

According to the inter-layer differential type remaining oil, the representative well is selected, and single well geological model is established. The production status of each layer is combined and the remaining oil potential is analyzed, the production plan is designed in layers. Orthogonal test method is used to carry out the orthogonal experiment design of the relevant parameters of oil well production measures. At the same time, the numerical simulation method is used to carry out numerical simulation and optimize injection and production parameters. In this way, combining with the economic benefit analysis under the current low oil price, the best solution is obtained by obtaining the maximum crude output and the economic limit oil gas ratio greater than 0.2 as the evaluation standard.

Aiming at the high-level intervals in the oil wells with different layers, then take nitrogen foam profile control measures to adjust the suction profile, and optimize the optimal nitrogen foam injection parameters are: volume of nitrogen foam injection is 0.2pv, foam concentration is 0.5%, gas-liquid ratio is 2: 1, cycle steam injection volume is 100t/m.

The results show that the oil production is the largest in the second round of profile control, the average daily oil production is 3.89t, and the cycle oil-gas ratio reaches 0.32. On this basis, continue to increase the profile control round, after the profile control 5 rounds, the average daily oil production is 3.18t, the average oil-gas ratio is 0.26, the cycle of cumulative oil production is 1431.23t, and the program implementation effect is getting better. It shows that nitrogen foam profile control can obviously reduce the ineffective and inefficient channeling of steam in the low remaining oil saturation zone and improve the development effect of steam huff and puff.

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