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Nitrogen Foam Profile Control for Heavy Oil Reservoir

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Abstract

In view of the character of heavy oil reservoir in Shengli oilfield under thermal production, the analysis that heterogeneity of oil reservoir, viscosity of crude oil, oil thickness, recovery efficiency of recoverable reserves and distance to the oil-water boundary affect the effectiveness of nitrogen foam profile control was made by reservoir numerical simulation and statistical interpretation of production effect of some wells which had being implemented nitrogen foam profile control. On that basis, a prediction model of nitrogen foam profile control technology was founded by means of the fuzzy comprehensive evaluation, and the reservoir conditions which adapt to nitrogen foam profile are presented. The results The adaptive research of nitrogen foam profile control in steam stimulation reservoir can enhance the pertinence and effectiveness of nitrogen foam profile control technology and improve the efficiency of multi-round steam stimulation in heavy oil reservoir.

Key words: Nitrogen foam; Numerical simulation; Field statistics; Adaptability to reservoir; Fuzzy evaluation

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INTRODUCTION

Steam stimulation of heavy oil reservoir development accounted for more than 95% of the thermal oil recovery reservoir in Shengli oilfield. Most of them has entered medium or late stage. The differences of the oil-water mobility and formation heterogeneity lead to serious steam channeling, low steam sweep efficiency. In conclusion the remaining oil which is rich in the low permeability zone cannot be effectively utilized and the development of the reservoir is poor. Nitrogen foam profile control technology has been widely used to solve these problems. Nitrogen foam (Wang & 2002; Li, He & Tang, 2006) has high apparent viscosity which can improve the oil-water mobility ratio, improve sweep efficiency of steam and displacement efficiency so that the effect of steam stimulation of heavy oil reservoir can be improved. But the field application indicates that the effect of nitrogen foam profile control can be affected by reservoir conditions and formation fluid properties seriously. Therefore researching reservoir adaptability of nitrogen foam profile technology has important guiding significance in exerting the excellent blocking performance of foam, avoiding the risk that may arise in the process in the implementation process and the large-scale applications of nitrogen foam profile.

1 INFLUENCING FACTORS ANALYSIS FOR NITROGEN FOAM PROFILE CONTROL

There are many types of heavy oil reservoirs in Shengli oilfield, and the geological conditions are complex, including the thick sandstone heavy oil reservoir with active edge and bottom water, the thin layer glutenite Super Heavy reservoir with edge water, thin interbedded sandstone heavy oil reservoir, the carbonate fractured Buried Hill in Super Heavy Oil Reservoirs with active edge and bottom water and the small fault block sandstone heavy oil reservoir. The analysis of nitrogen foam profile influencing factors is based on numerical simulation prediction and field statistics. In view of the character of heavy oil reservoir in Shengli oilfield,four types of oil reservoirs are mainly considered in the Numerical Simulation (Li, 2008), including the weak edge and bottom water, strong bottom water, strong edge water and multiple rounds throughput. Site statistics are aimed at the 402 wells in Gudao, Gudong Binnan and Xianhe oil production plant in Shengli Oilfield during 2006-2010, analyzing the effect on production, combining reservoir geology, develop dynamic, fluid properties, and construction techniques.

1.1 Impact of the Reservoir Heterogeneity on the Efficiency of Nitrogen Foam Profile

Having selected different permeability ratios (Yang, Lin, & Liu, 2004), and comparatived cycle incremental oil of the measures well, calculated results and field statistical results show that, nitrogen foam is suitable for heavy oil reservoir which has a certain heterogeneity. But yield increase of crude oil decreased sharply after the permeability ratio is greater than 4:1 which means nitrogen foam's ability of blocking large pore is still limited. Once the water channeling channels formed in large quantities, it is difficult to achieve a comprehensive and effective closure.

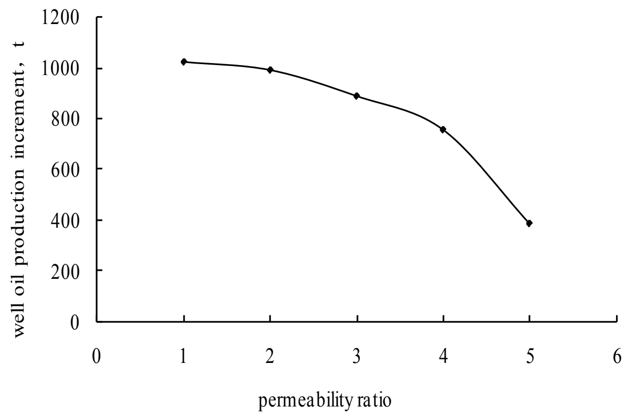

Figure 1
Nitrogen Foam Profile Production Effect Indifferent Permeability Contrast Condition

1.2 Impact of the Oil Viscosity on the Efficiency of Nitrogen Foam Profile

Select the oil whose viscosity is between 1000 to 100000mPa.s (50 ℃), forecast the effect of profile modification and collect the site statistics. Results show that (Figure 2), with the increase of viscosity (Liu, Liu, & Li, 2009), cycle incremental oil reduced. When the viscosity is below 20000 mPa.s, the cycle incremental oil is greater than 800t. When the viscosity is between 20000mPa.s to 40000 mPa.s, the cycle incremental oil is between 600 to 800t. When the viscosity is higher than 40000 mPa.s, the measures are usually valid for a short time and the cycle incremental oil is less than 600t.

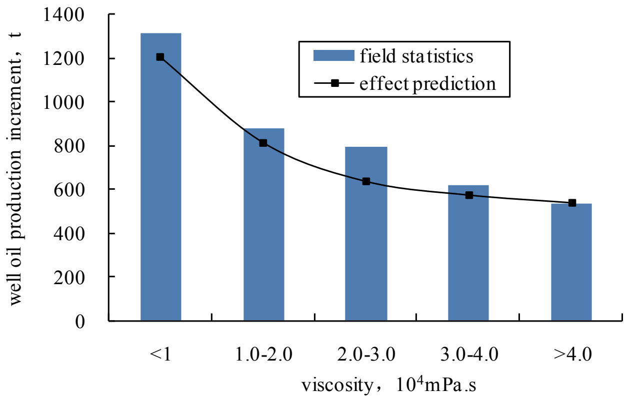

Figure 2
Nitrogen Foam Profile Production Effect for Different Crude Oil Viscosity

1.3 Impact of the Oil Layer Thickness on the Efficiency of Nitrogen Foam Profile

The difference in density and viscosity between steam and crude oil often leads to steam gravity onlap, making the steam swept volume reduce. So contrast nitrogen foam profile effect when reservoir thickness is between 2 ~ 20 m. The results show that: the foam profile has significantly improved the crude oil production. With the oil layer thickness increasing, the cycle oil production is also increasing. But stimulation ratio reduced after 12m (Stimulation ratio = (production measures - measures before production) / measures before production). For thin layer, although the gravity onlap phenomenon is not serious, steam flow decreased because of the foam, which effectively suppress the fingering of steam and steam channeling, so that the steam swept volume increases,but still have the effect of increasing oil. However, to the reservoir thinner than 4 m, the results are not very satisfactory due to poor own the material basis. To the reservoir thicker than 20 m, the serious foam gravity segregation phenomenon weakens plugging strength. So the effect of profile control will deteriorate too.

Table 1
Nitrogen Foam Profile Production Effect in Different Reservoir Thickness Condition

Reservoir thickness, m	Stimulation ratio
2	0.944
4	1.048
6	1.169

To be continued

Continued

Reservoir thickness, m	Stimulation ratio
8	1.221
10	1.244
12	1.272
14	1.024
16	0.905
20	0.775

1.4 Impact of the Recoverable Reserves Recovery Ratio on the Efficiency of Nitrogen Foam Profile

Site statistical results (Table 2) show that, the cycle Incremental oil increased with the recoverable reserves recovery ratio (Yu, Liu, & Zhang, 2012) increases. When the recoverable reserves recovery ratio is greater than 80%, the cycle incremental oil significantly reduced. Therefore, the nitrogen foam is an effective means to improve the efficiency of multi-round steam stimulation in heavy oil reservoir.

Table 2
Production Performance Statistics of Wells With Different Recovery Rate of Recoverable Reserves Using Nitrogen Foam

Recovery rate of recoverable reserves, %	Cycle incremental oil, t
0-0.1	712.2
0.1-0.2	985.3
0.2-0.3	1113.5
0.3-0.4	1231.5
0.4-0.5	1293.1
0.5-0.6	1668.3
0.6-0.7	1520.1
0.7-0.8	1731.8
>0.8	1074.5

1.5 Impact of Distance Away From the Oil-Water Boundary on the Efficiency of Nitrogen Foam Profile

The steam stimulation is a long-term antihypertensive mining process. The cycle oil production and the length of production valid period are closely related to reservoir pressure. So the effect of nitrogen foam profile has a great relationship with the distance away from the oil-water boundary. Contrast the effects of nitrogen foam profile production when the distance away from the oil-water boundary (Wang & Dang, 2010) is between 50 ~ 1000 m. The results show that, if the distance away from the oil-water boundary is too short, the blocking strength of the foam is not sufficient to suppress edge water propulsion and the efficiency is not obvious. To the production wells which are too far away, the reservoir pressure is relatively low. So the anti-handling ability of stimulation wells is not strong even if injected foam and the efficiency of foam profile is also not very significant. Numerical simulation predicted results and live statistics both show that, the incremental oil is higher when the distance ranges from 300 m to 500 m. Therefore, choose the oil and water wells whose distance away from the boundary ranges from 300 m to 500 m to take measures so that the efficiency of nitrogen foam profile is significant.

Table 3
Nitrogen Foam Profile Control Technique Application Data Statistics for Different Oil/Water Boundary Well

Distance away from the oil-water boundary, m	Cycle incremental oil, t
<100	646.5
100-200	771.9
200-300	667.5
300-400	1482.0
400-500	1092.9
>500	344.1

2 FUZZY COMPREHENSIVE EVALUATION ON THE EFFICIENCY OF NITROGEN FOAM PROFILE

This article is aimed at using the fuzzy transform principle and the principle of maximum degree of membership to form a fuzzy evaluation method of nitrogen foam profile control technology application effect on the basis of the numerical simulation predictions and site statistical analysis and research results. This method takes into account the mathematical relationship between the profile control effect of each of the major factors and impact indicators, structures evaluation matrix on the basis of the scene and forecast data, uses the expert scoring method to determine the weight set for evaluating and decides when to apply the nitrogen foam profile control technology in the stimulation wells.

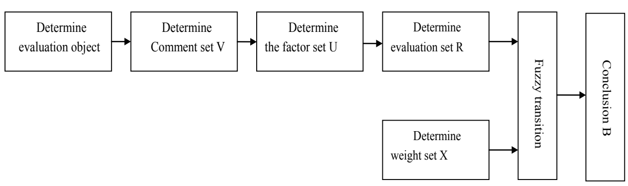

Figure 3
Fuzzy Comprehensive Evaluation Flowchart

Fuzzy comprehensive evaluation method (Meng, Chen, & Zhang, 2006) is to apply the fuzzy transform principle and the principle of maximum degree of membership, consider the various factors associated with the evaluation object and make comprehensive evaluation. Use the theory of fuzzy comprehensive evaluation to choose the nitrogen foam profile wells according to the main factors and criteria of the test wells' production. Major steps of using fuzzy comprehensive evaluation is as shown in Figure 3.

(a) Determine the evaluation object. Generally we call things that are evaluated as evaluation object. The evaluation object of this study was the effectiveness of nitrogen foam profile control. The results were showed by a fuzzy set V which was made up by a group of comments. While all the factors that affected evaluation results composed a factor set U.

(b) Determine the comment set: $V = (v_1, v_2 \cdots v_n)$. According to the evaluation hierarchies of evaluation object, the corresponding comment set: (best, better, medium, worse, worst), or it could be made up of discretization numerical in a certain interval, the numbers represented membership grade of the comment. Evaluation result $\tilde{Y} = (y_1, y_2 \cdots y_m)$ was a fuzzy subset of V, while y_i stood for the evaluation degree of evaluation object by v_i .

(c) Determine the factor set: $U = (u_1, u_2 \cdots u_n)$ .A set which consisted of all the factors that affected the result was called factor set, for example, we could evaluate the evaluation object on the basis of the factor u_i , as a result, it was called the single factor evaluation $r_i = (r_{11}, r_{12} \cdots r_{im})$.

According to the field statistics analysis and numerical simulation forecast result of nitrogen foam profile control in Shengli oilfield, those factors such as heterogeneity of oil reservoir, viscosity of crude oil, oil thickness, recovery efficiency of recoverable reserves and distance to the oil-water boundary played an important role in profile control implementation, so we recorded the factor set for this study as $U = (u_1, u_2, u_3, u_4, u_5)$ = [heterogeneity of oil reservoir, viscosity of crude oil, oil thickness, recovery efficiency of recoverable reserves, distance to the oil-water boundary].

(d) Determine r_i to form evaluation array: $R = [r_{ij}]_{n\times m}$.

(e) Determine weight set: $X = (x_1, x_2 \cdots x_n)$.We could get x_i by evaluation factor u_i, a set which made up of x_i called weight set or weight vector.

We invited some experts to give their scores then calculated the average score, the result showed the influence weight of five factors as following:

$$X = (x_1, x_2, x_3, x_4, x_5) = \left(\frac{1}{4}, \frac{1}{5}, \frac{3}{20}, \frac{1}{5}, \frac{1}{5}\right)$$

(f) Use fuzzy comprehensive evaluation model for judgment: $M(\Lambda, \oplus)$, $b_j = \min\left\{1, \sum_{i=1}^{n}(x_i, r_{ij})\right\}$, $B = X \otimes R$ as following:

$$B = X \otimes R = (x_1, x_2, x_3, x_4, x_5) \otimes \begin{bmatrix} r11 & r12 & r13 & r14 & r15 \\ r21 & r22 & r23 & r24 & r25 \\ r31 & r32 & r33 & r34 & r35 \\ r41 & r42 & r43 & r44 & r45 \\ r51 & r52 & r53 & r54 & r55 \end{bmatrix} \quad (1)$$

According to maximum membership principle, max(b_1, b_2, b_3, b_4, b_5), the conclusion that was the result of the steam soak well nitrogen foam profile control application: v_i (i = 1,2,3,4,5).

On the basis of analysis the five factors by the statistics and numerical simulation technology, we formed an open data source and combined the fuzzy comprehensive evaluation to build prediction model and develop prediction software of nitrogen foam profile control technique adaptive.

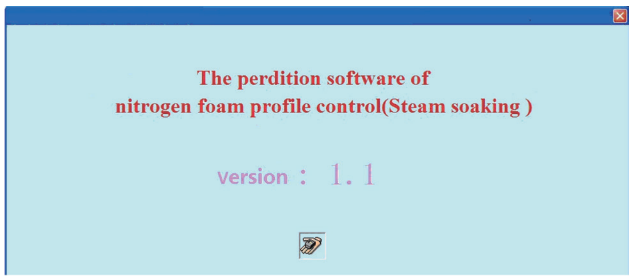

Figure 4
The Prediction Software of the Nitrogen Foam Profile Control

3. FIELD APPLICATION AND EFFECT EVALUATION

The nitrogen foam profile control technique and the prediction model was applied to the Well 402 of Shengli oilfield from 2006 to 2010, the prediction result accord with the Well 350, and the coincidence rate is 87.06%.

Under the guide of the prediction model of nitrogen foam profile control technique application, nitrogen foam profile control has been carried out in many blocks since 2009, the average per well production increment was 649.15t, and well composite water cut has dropped 10.2%, gas oil ratio increased by 0.271.

Since April 2005, the production well GDD0N506 has been produced for more than 1730 days, and it was in the end of the production period at the moment, water percentage raised to 98.5%.On May 11th, 2010, the well was started up, before the profile control technique was applied, average daily fluid production rate was 56.6m^3, average daily oil production rate was 2.4t, water percentage was 95.7%. However, after this technique was used, the average daily fluid production rate was 55.6m^3, average daily oil production rate was 18.5t, water percentage was 66.6%, cumulative oil production was 2533.8t, and cumulative oil was 1835.4 t.

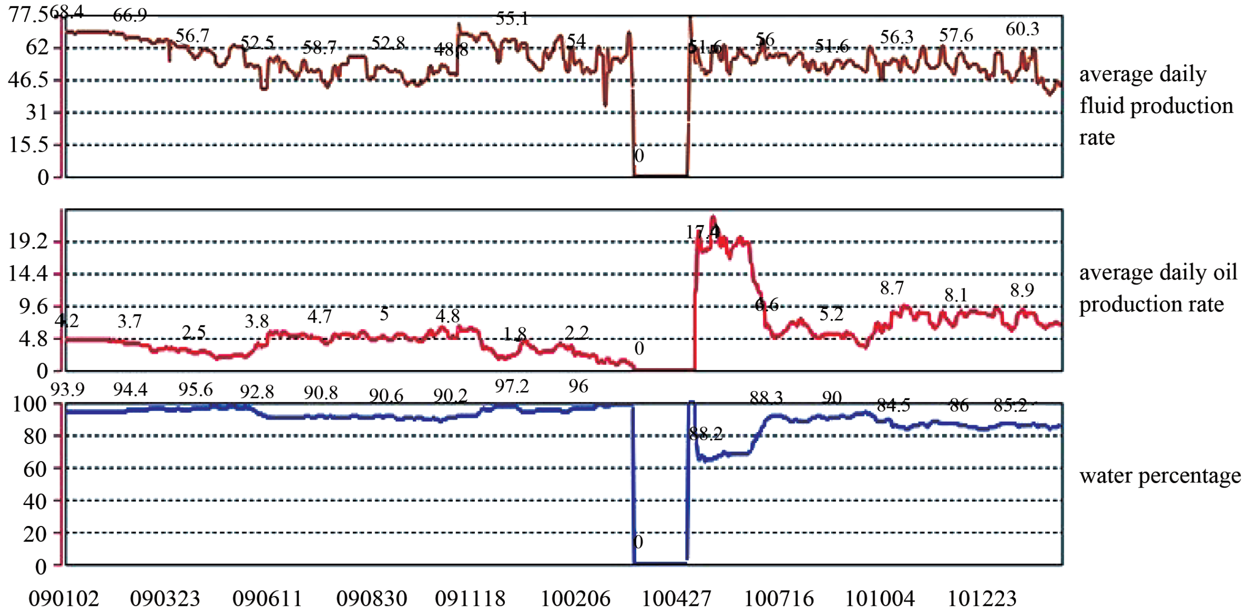

Figure 5
The Production Effect Contrast Before and After the Profile Control Technique for Well GDD0N506

CONCLUSION

• Combined reservoir geology, develop dynamic, fluid properties and so on to analyze the effect on production, and studied nitrogen foam profile influencing factors using numerical simulation and field statistics. The adaptable reservoir conditions of nitrogen foam profile is obtained: permeability ratio is less than 4; crude oil viscosity is below 4.0×10^4mPa·s; oil thickness is between 4 m to 12m; the opportune moment is middle and later period of multicycle steam stimulation ; the distance to the oil-water boundary is between 300 m to 500 m.

• Nitrogen foam profile control technique was applied to the Well 402 of Shengli oilfield from 2006 to 2010; the coincidence rate of prediction model is 87.06%.It means that this technique can guide the operation correctly.

• The applications of nitrogen foam profile control technique indicate that on the basis of selection of test well reasonably, this technique can improve the developing effect of high water cut heavy oil reservoir. The average per-well oil increased was 649.15t, well composite water cut has dropped by10.2%, gas oil ratio increased by 0.271.

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