CSCanada
Advances in Petroleum Exploration and Development
Vol. 13, No. 1, 2017, pp. 1-8
DOI:10.3968/9088

ISSN 1925-542X [Print]
ISSN 1925-5438 [Online]
www.cscanada.net
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Research and Practice on Gas Channeling Controlling by Combined Stimulation for Multi-Thermal Fluids Huff and Puff

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Supported by the CNOOC Major Project of "Key Technology Research of Thermal Recovery About Multi-thermal Fluids Stimulation, Cycle Steam Stimulation and SAGD" (YXKY-2013-TJ-01) of CNOOC (China) Co., LTD.

Received 29 December 2016; accepted 15 February 2017
Published online 26 March 2017

Abstract

Cycle steam stimulation has been widely used in land oil field. In order to get higher oil recovery rate and higher cumulative oil production, one improvement work of cyclic steam stimulation is injection N_2 and CO_2 together with steam to enlarge the heated radius, and the pilot test of multi-thermal fluids huff and puff were carried out in offshore heavy oil in Bohai. There were 10 horizontal wells which have accomplished the 1st cycle stimulation, and 6 wells have accomplished the 2nd cycle stimulation. There were 4 well times of gas channeling in the 1st cycle injection, and 9 well times in the 2nd cycle injection. Because of the formation pressure drop, gas channeling became more serious with the increase of stimulation cycles. Based on the well performance, the reason and characteristic of gas channeling for injection multi-thermal fluids were analyzed, which is different from that of steam injection. Based on a numerical model, a quantitative researched about the influence of gas channel to thermal well was carried out. In order to manage the gas channeling, a combined stimulation program was purposed. Case study of gas channeling controlling by combined stimulation in N heavy oil field in Bohai shows that, the combined stimulation can relieve the risk of gas channeling. The new multi-thermal fluids injection model is of great significance for thermal recovery of offshore heavy oil.

Key words: Gas channeling; Combined stimulation; Multi-thermal fluids; Offshore heavy oil

Ma, K. Q., & Liu, D. (2017). Research and Practice on Gas Channeling Controlling by Combined Stimulation for Multi-Thermal Fluids Huff and Puff. *Advances in Petroleum Exploration and Development*, *13*(1), 1-8. Available from: http://www.cscanada.net/index.php/aped/article/view/9088
DOI: http://dx.doi.org/10.3968/9088

INTRODUCTION

Steam injection technology of heavy oil reservoirs is the most commercially successful EOR method [1-4]. Nowadays, the cycle steam stimulation (CSS), which is known as the most widely used and mature technology, recently was introduced for offshore heavy oil recovery[5-6]. A variation on this recovery process is to co- inject N_2 and CO_2 with steam[7].

The oil viscosity of N heavy oil field is 450-950 mPa·s in formation condition. In order to improve the development effect, the Bohai Oilfield has built the first thermal recovery pilot test area. Currently offshore heavy oil thermal recovery pilot test has been carried out which takes the advantage of a synergistic effect made from N_2 and CO_2 with steam. By the end of 2016, there have been 10 wells which completed the 1st cycle of thermal recovery stimulation, and 6 wells which completed the 2nd cycle stimulation. There were 4 well times of gas channeling in the 1st cycle injection, and 9 well times in the 2nd cycle injection. Because of the formation pressure drop, gas channeling became more serious with the increase of stimulation cycles. If early preventive and post treatment measures were not taken in a timely manner, gas channeling will aggravate, which will affect the effect of multi-thermal fluids huff and puff. So it is necessary to carry out quantitative analysis of influencing factors and rules, and provide reference for reducing gas channeling risk.

1. CHARACTERISTICS OF GAS CHANNELING FOR INJECTION MULTI-THERMAL FLUIDS

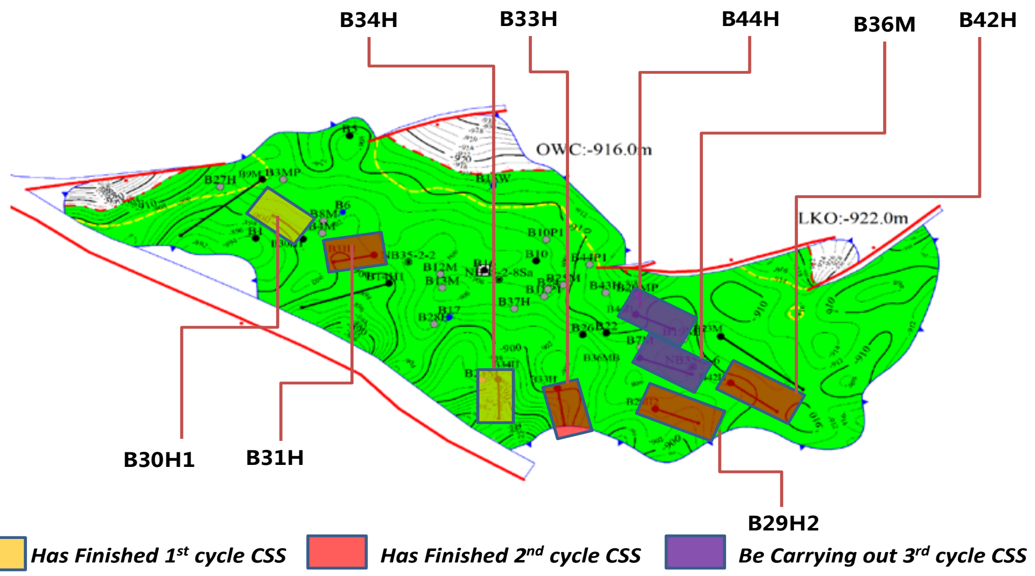


Figure 1
Thermal Wells for Multi-Thermal Fluids Stimulation of N Heavy Oil Field

The characteristics of gas channeling for multi-thermal fluids are different from that of steam stimulation. All of thermal wells of N heavy oil field were located in three major layers. Figure 1 is one of a major layer, and there are 8 wells located here. Based on the performance of well B29H2, B36M and B44H, the characteristic of gas channeling for injection multi-thermal fluids can be analyzed.

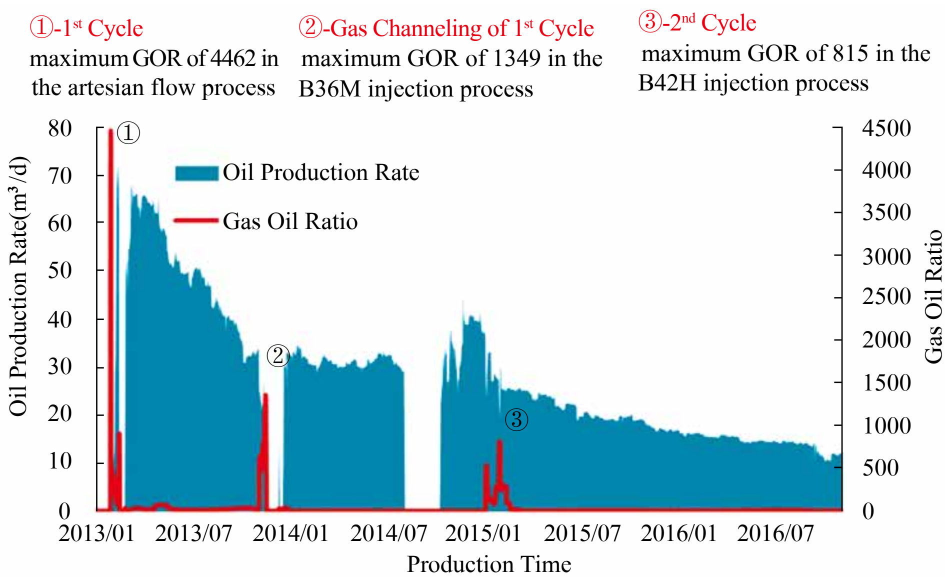


Figure 2
Production Dynamic Curve of Well B29H2 for Multi-Thermal Fluids Stimulation

Figure 2 is the performance of well B29H2, which has accomplished two cycles of multi-thermal fluids stimulation. The value of gas-oil ratio (GOR) can reflect the gas channeling. The normal value of GOR is about 3-5, but the value can be very high if gas channeling happened. There are three high points of GOR during B29H2 whole production process. The first high point appeared in the artesian flow process after soaking for several days in the process of first injection cycle, with the maximum GOR of 4462. The second one happened in the B36M injection process, with the maximum GOR of 1349. The pump has to be stopped, and restarted after B36M injection process completed. The third one happed in the second injection, at that moment, B42H is injecting, and with the maximum GOR of 815. Pump can operate normally at this level, so the pump was not stopped.

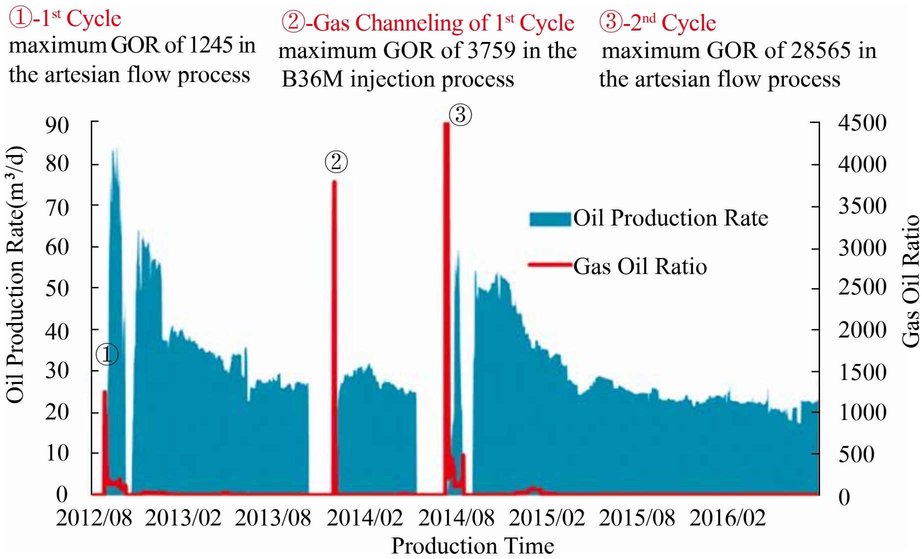


Figure 3
Production Dynamic Curve of Well B44H for Multi-Thermal Fluids Stimulation

Figure 3 is the performance of another well of B44H, which also has accomplished two cycles of multi-thermal fluids stimulation and located nearby well B36M. The normal GOR value of B44H is about 5, but the value can be very high if gas channeling happened. There also are three high points of GOR. The first high point appeared in the artesian flow process after soaking for several days in the process of first injection cycle, with the maximum GOR of 1245. The second one happened in the B36M injection process, with the maximum GOR of 3759. The pump has to be stopped, and restarted after B36M injection process completed. The third one happed after the second injection cycle of B44H, with the maximum GOR of 28565.

In summary, the gas channeling problem of nitrogen and carbon dioxide in the offshore is different from the "steam channeling" characteristics of the steam stimulation in the onshore oil field. Field practice results show that the multi-thermal fluids "gas channeling" seriously affected the effect of the well and adjacent wells. For the thermal recovery well which is injecting, there is some phenomenon after gas channeling, such as the production GOR increased, flow back temperature decreased, and oil productivity declined. And as for the surrounding well which is producing, there is some phenomenon after gas channeling, such as gas production rate increased, but oil and temperature have no change. The displacement effect of gas is not obvious. Gas channeling has become a difficult problem to restrict the application of multi-thermal fluid technology.

2. QUANTITATIVE RESEARCH OF GAS CHANNEL INFLUENCE WITH NUMERICAL MODEL

2.1 Numerical Model of Gas Channeling

The main factors that affect the flow between heavy oil wells include: the heterogeneity of reservoir, the presence of micro fracture or high permeability, unreasonable injection and production parameters, and high pressure difference, too small well spacing and so on[8]. Based on the typical reservoir and thermal parameters of N oil field, which shown in Table 1, a numerical model was built to carry out quantitative research.

Table 1
Typical Reservoir and Thermal Parameters of N Oil Field in Numerical Model

Parameter name	Value	Parameter name	Value
Initial reservoir temperature/℃	50	Rock compressibility/kPa^{-1}	5×10^{-6}
Formation oil viscosity /mPa·s	500	Upper and lower rock volume heat capacity/($kJ\cdot m^{-3}\cdot C^{-1}$)	2200
Formation permeability /mD	5000	Upper and lower rock thermal conductivity/($kJ\cdot m^{-1}\cdot d^{-1}\cdot C^{-1}$)	105

To be continued

Continued

Parameter name	Value	Parameter name	Value
Horizontal well length /m	160	Rock Thermal Conductivity/(kJ·m^{-1}·d^{-1}·C^{-1})	163
Crude oil reserves/m^3	11.6×10^4	Water Injection Rate /(m^3·Day^{-1})	200
Relative density of crude oil	0.956	Gas Injection Rate /(Nm^3·Day^{-1})	5×10^4
Oil thermal expansion coefficient/℃$^{-1}$	1.0×10^{-6}	N_2 Volume Ratio /%	85
Specific heat for oil/(kJ·kg^{-1}·℃$^{-1}$)	2.12	CO_2 Volume Ratio /%	15
Oil compressibility/MPa^{-1}	5.3×10^{-4}	Steam injection time /d	29
Rock volume heat capacity/(kJ·m^{-3}·C^{-1})	2575	soak time /d	3

The numerical model is available by the thermal reservoir simulator, STARS, which is shown in Figure 4. In addition, the grid system is 100 × 101 × 10 and the corresponding block dimensions in *I*, *J* and *K* directions are 2.0 m, 2.0 m and 1.0 m, respectively. And the border is a closed border. The reservoir thickness is 10 m in the model, and the horizontal well located in the center of reservoir with horizontal section length of 160 m.

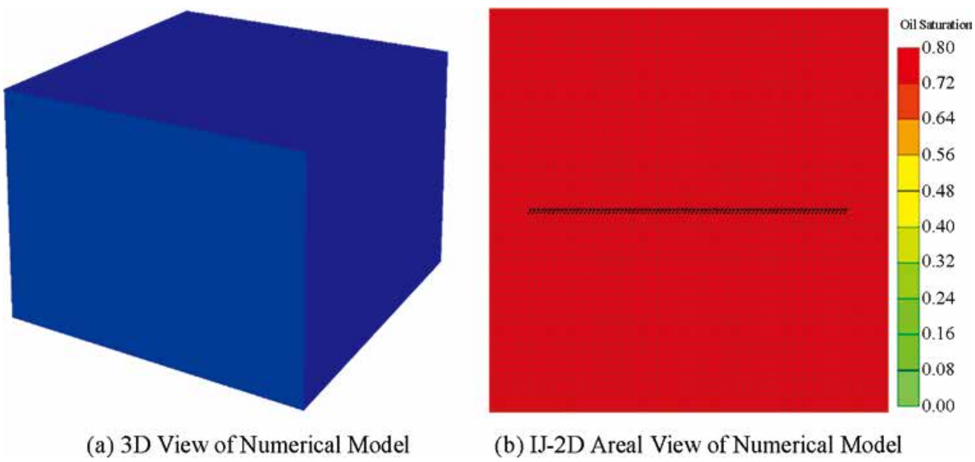


Figure 4
Diagram for the Horizontal Well of Cycle Multi-Thermal Fluids Stimulation

The other basic parameters of the reservoir model are as follows: the vertical permeability is 500×10^{-3} μm^2, the original oil saturation is 0.728, the porosity is 35%, the reservoir depth is 1000 m, the initial formation pressure is 10.0 MPa.

2.2 Numerical Simulation Project Design

By adjusting the value of AVG in the CMG software, which is a coefficient in the power-law correlation for temperature dependence of gas-phase viscosity, to change the gas flow ability in the formation, and nitrogen and carbon dioxide gas channeling in the formation can be equivalent simulated. Two tests of N_2 and CO_2 channeling condition were designed for comparative research, which was shown in Table 2.

Table 2
Tests Design of Gas Channeling Equivalent Simulated

Test #	Injection media	Cum. water injection / (m^3)	Water injection rate(m^3/Day)	Gas injection rate (Nm^3/Day)	Gas viscosity (mPa.s)
Test 1	Water+15%CO_2+85%N_2	5800	200	5×10^4	0.1
Test 2	Water+15%CO_2+85%N_2	5800	200	5×10^4	1.0

2.3 Production Performance Comparison

Figure 5 is the well performance comparison of Test 1 and Test 2, which represents gas channeling and no gas channeling respectively. The values of oil production rate are both demonstrate a trend of increased at the beginning and reduced later. But the well of gas channeling happened (Test 1) have lower oil production rate than that of gas channeling not happened (Test 2).

That is, if gas spread more far away from the injection well, the oil production rate declined more rapidly. And the cumulative oil production of gas channeling happened (Test 1) has 2,000 m^3 lower than that of gas channeling not happened (Test 2). That is, gas channeling reduce about 2,000 m^3 oil production in one injection cycle, which is the reason of poor well performance in the cycle process.

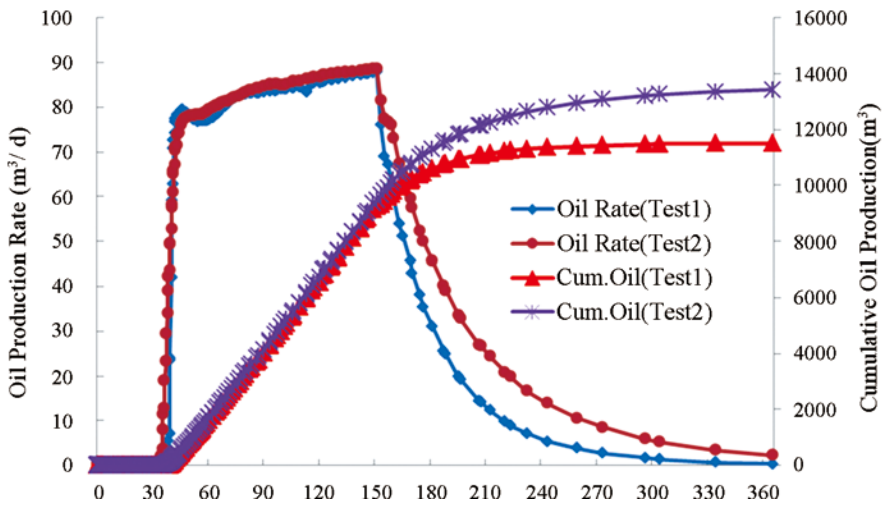
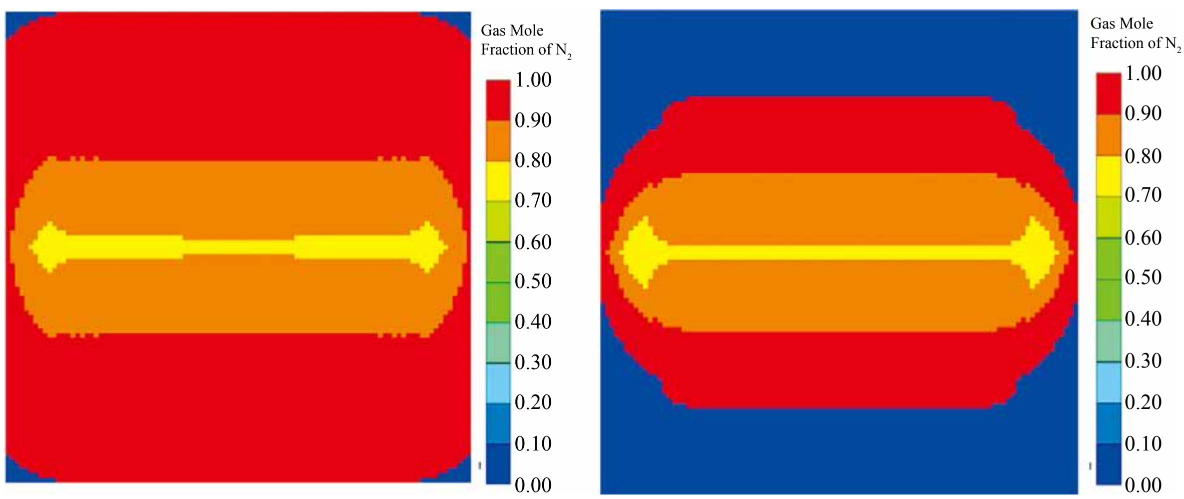


Figure 5
Production Performance Comparison of Cycle Multi-Thermal Fluids Stimulation

2.4 Analysis and Discussion

In order to analyze the difference of gas channeling, the gas mole fraction of N_2 and CO_2 after Injection multi-thermal fluids in the 1st cycle were compared.

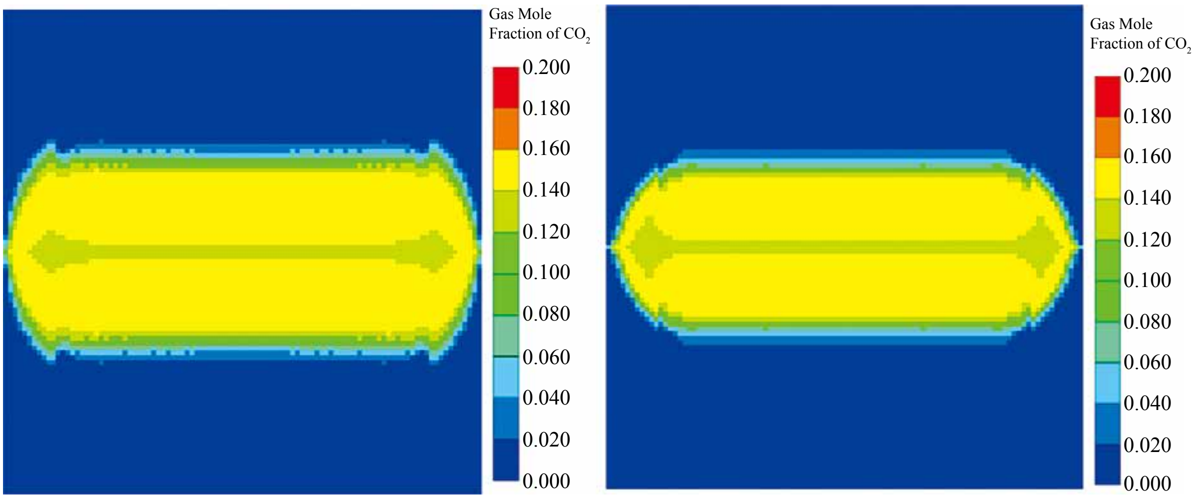


(a) Gas Channeling Happened (b) Gas Channeling Not Happened

Figure 6
Gas Mole Fraction of N_2 After Injection Multi-Thermal Fluids in the 1st Cycle

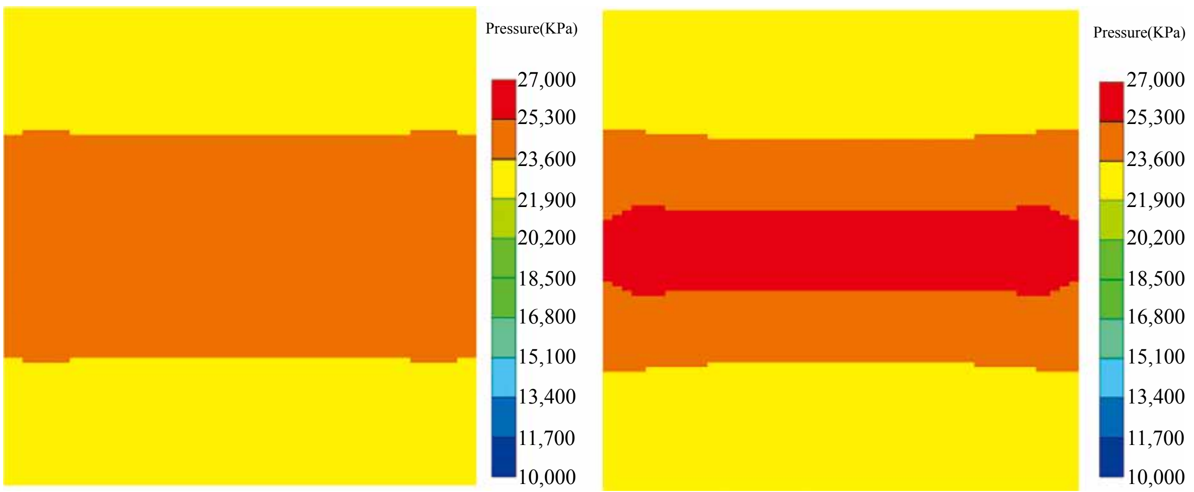
Figure 6 is the comparison of gas mole fraction of N_2 after injection multi-thermal fluids in the 1st cycle. Swept area of gas channeling happened wells was nearly two times of that of gas channeling not happened wells.

Figure 7 is the comparison of gas mole fraction of CO_2 after injection multi-thermal fluids in the 1st cycle. Swept area of gas channeling happened wells was little bigger than that of gas channeling not happened wells. In a word, it can be concluded from Figire 6 and Figiure 7, N_2 is spread faster than that of CO_2, and is the main reason of gas channel happening. That is because the CO_2 can dissolve in the crude oil easier and reduce the oil viscosity more effectively than that of N_2.



(a) Gas Channeling Happened (b) Gas Channeling Not Happened

Figure 7
Gas Mole Fraction of CO_2 After Injection Multi-Thermal Fluids in the 1st Cycle



(a) Gas Channeling Happened (b) Gas Channeling Not Happened

Figure 8
Pressure After Injection Multi-Thermal Fluids in the 1st Cycle

Figure 8 is the comparison of reservoir pressure after injection multi-thermal fluids in the 1st cycle. Pressure of gas channeling happened well has lower but uniform pressure distribution, and gas channeling not happened well has an area of high pressure accumulation area. A revelation can be got from above figures, that multi-thermal fluids can relieve gas channeling risk by decreasing the proportion of N_2 in the gas.

2.5 Combined Stimulation Program Design

For comprehensive utilization of injection heat and adjusting the pressure balance to solve the gas channeling problem, a combined stimulation program, that is several wells injection and production were carried out simultaneously, was suggested. Numerical research result of actual reservoir model of Bohai N oilfield was shown in Table 3. Single well injection rate was 150 m^3/d, and single well cycle injection volume was 4,500 m^3, began soaking and producing at the same time, and production two cycles.

Table 3
Production Effect Comparison of Combined Stimulation and Stimulated in Turn

Test #	Program name	Scheme described
Test 3	Combined stimulation	B29H2,B33H,B36M, B42H and B44H injection multi-thermal fluids at the same time
Test 4	Stimulated in turn	B29H2,B33H,B36M, B42H and B44H injection multi-thermal fluids one by one (that is, B33H start to inject after B29H2 completed)

The cumulative oil production volume of Test 3 and Test 4 is $16.8\times10^4m^3$ and $13.6\times10^4m^3$ respectively. The average well oil increment is about $0.64\times10^4m^3$ of combined stimulation. So it is an effective way to relieve gas channeling.

3. CASE STUDY OF PILOT TEST

Based on the research, the pilot test of combined stimulation has been carried out in 2016. Two wells of B36M and B44H, which both has finished the second cycle stimulation, have serious gas channeling problem in 1st and 2nd cycle injection. In the third cycle injection, combined stimulation program was applied. B36M and B44H started to inject multi-thermal fluids at the same time on September 12, and the cumulative water injection volume of B36M and B44H was 2,101 m^3 and 2,112 m^3 respectively. And the wellhead pressure after injection process was 6.2 MPa and 7.1 MPa respectively.

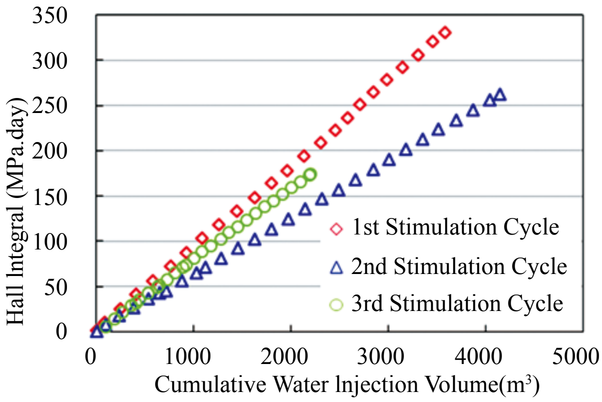


Figure 9
Hall Integral Curve of B36M

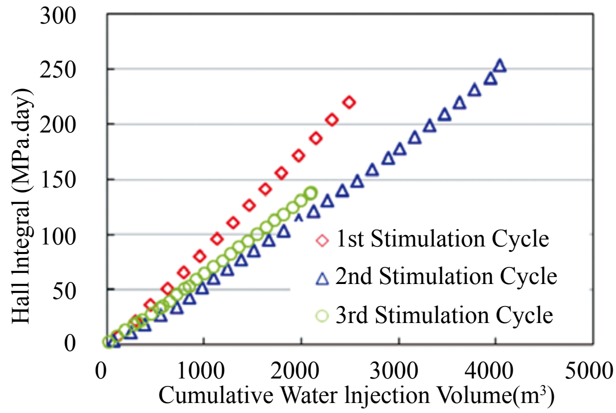


Figure 10
Hall Integral Curve of B44H

Because these 5 wells has serious gas channeling in the first and second cycle injection, in order to relieve the gas channeling among B36M-B44H and B29H2-B33H-B42H, a weak gel slug of about 250 m^3 was injected before multi-thermal fluids injection.

Figure 9 and Figure 10 are the hall integral curve of B36M and B44H. The hall integral curve can be used to evaluate the performance of injection. From the figures, the curve slope of B36M in the 1st cycle is higher than that of 2nd cycle. The same trend is appeared in B44H. So it can be concluded that, the curve slope decreased with stimulation cycles increased. It means that it is easier to inject in the latter cycle stimulation, and the gas channeling may be one reason. But the slope of 3rd stimulation cycle has some difference. It is bigger than that of 2nd cycle; both B36M and B44H have the same situation, which was shown in Table 4.

Table 4
Comparative of Hall Integral Curve Slope

Well names	1st stimulation cycle	2nd stimulation cycle	3rd stimulation cycle
B36M	0.092	0.063	0.080
B44H	0.089	0.063	0.066

One obvious reason is that, weak gel and combined stimulation relieve the gas channeling. So during the injection process, the surrounding wells, such as B33H, B29H2 and B42H have no significant gas channeling problem and no well shut in due to gas channeling. Up to now, these two wells started to production with pump, and the oil rate are $45m^3/d$ and $32m^3/d$ and water cut percent are 20% and 14% for B36M and B44H respectively.

CONCLUSION

(a) Because of the formation pressure drop with the increase of stimulation cycles, gas channeling became more serious, and affected the development effect. Based on the well performance of field, the characteristic of gas channeling for injection multi-thermal fluids were analyzed, which is different from that of steam injection.

(b) Based on a numerical model, a quantitative researched about the influence of gas channel to thermal well was carried out, and a combined stimulation program was purposed.

(c) Case study of gas channeling controlling by combined stimulation in N heavy oil field in Bohai shows that, the combined stimulation can relieve the risk of gas channeling.

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