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The Mechanism of HDNS and Study on Programme Optimization

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Abstract
The shallow and thin layer heavy oil reservoir of Pai-601 block in Xinjiang adopts HDNS (horizontal well+ dissolver + nitrogen gas+ steam injection) to develop the heavy oil reservoir. It has made a significant effect, solving production problems of the block, such as: low natural energy, less thermal loss, and less oil cycle production. In order to improve the next process scheme, we have conducted a thorough study of its mechanism. The best HDNS's parameters of Pai-601 block were chosen as follows: steam injection is 9.5~10.5 m^3/m, nitrogen gas injection is 140~160 Nm^3/m and thinning agent's optimum dosage is 0.10 t/m.

Key words: Shallow and thin layer; Super heavy oil; The technology HDNS; Mechanism; Scheme optimization

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INTRODUCTION
Xi Yuan Chun Feng Oil Field in Dzungarian Basin is shallow and thin layer. Its oil was heavy with high crude oil viscosity, shallow embedment, low layer temperature, and the natural energy is insufficient. There is no liquidity under the condition of reservoir and no production under the conventional testing for oil. It has adopted HDNS (steam + nitrogen gas+ dissolver) to product from 2009. Extensive application of HDNS is from 2011 and has been operated in 181 wells which have made significantly economic benefits. All of them have proved that HDNS is effective technical approach of exploiting the super heavy oil in shallow and thin layer. However, the cost of HDNS increases considerably compared with pure steam injection in thermal recovery. Therefore, we have to reduce operating costs under the circumstances of improving the injection strength of steam, nitrogen gas and dissolver, which are the essential requirements of HDNS.

1. MECHANISM OF HDNS PROCESS LEADING EFFECT
HDNS is a technique to improve development effect of shallow, super heavy oil reservoir in horizontal well through taking advantage of the complex role of dissolver, nitrogen and steam to heavy oil (Song, 2003; Gao *et al*., 2003; Sun, 2012).

1.1 Effects of Horizontal Well
(1) Compared with vertical well, the horizontal well has a broader spilling area and larger steam sweep volume which lay the foundation of decreasing steam injection pressure, enhancing the quality of steam injection and reinjection water rate.

(2) Provide a stable gas-cap space for nitrogen injection and constantly supply formation energy by nitrogen gas roof insulation.

(3) Slow down the invasion speed of edge water and bottom water as well as prolong the producing cycle of a single well.

1.2 Effects of Dissolver
Dissolver (Chen *et al*., 2004) can enhance the oil recovery through reducing crude oil viscosity and steam injection start-up pressure and then improving steam displacement efficiency.

(1) Reduce oil viscosity

YR-2 dissolver was used in Pai601-Ping1 to test oil viscosity. The results show that under the temperature of 50 ℃, a 5% dosage brings about more than 73% viscosity reducing rate, a 10% dosage brings about more than 90% viscosity reducing rate.

(2) Reduce steam injection start-up pressure

Oil soluble viscosity reducers can greatly reduce the yield values (Li & Shi, 2001) of thick oil and then reduce the starting pressure of steam injection. The results of numerical simulation show that: steam injection accompanied with oil soluble viscosity reducers can reduce 1~2 MPa of the starting pressure of steam injection.

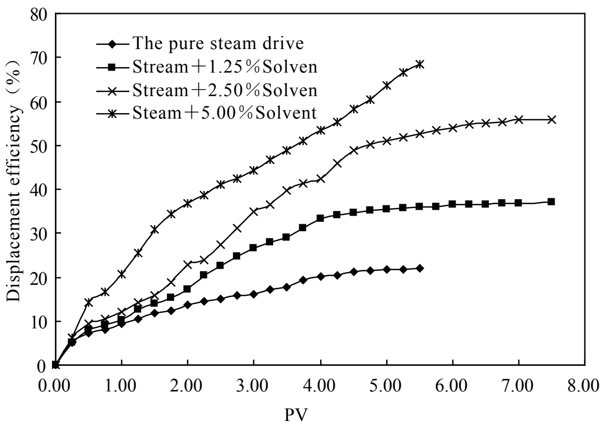

Figure 1
Oil Soluble Viscosity Reluctant´s Effect on Displacement Efficiency

(3) Improve the steam displacement efficiency

Oil soluble viscosity reducers greatly improve the steam displacement efficiency. The results of tube displacement experiment show that as the increase of oil soluble viscosity reducer injection rate, the displacement efficiency will increase continuously. When oil soluble viscosity reducers reach 5.0%, the displacement efficiency improves more than 35%.

1.3 Effects of Nitrogen Gas

The partial pressure of nitrogen gas (Yu *et al*., 2012), Jamin effect and gravity differentiation of micro air bubble can improve the heating range of steam. In thermal recovery, we can replenish formation energy and improve the recovery rate of water. In addition, the nitrogen gas can improve the elastic energy of oil and reduce the viscosity of the crude oil.

(1) Reduce wellbore heat loss

Through the laboratory test data, under the same steam injection velocity, when injection nitrogen gas the heat loss of wellbore will reduce 3-5% , this will improve bottom hole steam quality, and raise the utilization ratio of heat energy.

(2) Increase formation energy

Nitrogen is condensate gas with a higher expansibility than other gases (carbon dioxide, methane, flue gas and etc). So after nitrogen gas is injected into formation, we should replenish formation energy in time. It can accelerate crude oil flowing back from formation and improve liquid withdrawal velocity.

(3) Improve the steam displacement efficiency

Laboratory results showed that nitrogen can improve the displacement efficiency for 9.34% to 17.96% by strengthening the distillation, and further increasing the steam sweep volume and efficiency.

1.4 Effects of Steam

(1) Reducing the crude oil viscosity, flow resistance and the interfacial tension.

(2) Increasing formation energy and improve crude oil output.

2. THE OPTIMIZATION OF HDNS TECHNOLOGY SCHEME

In order to use the HDNS technology scheme in the entire row of 601 blocks, there need to set up multiple reservoir geological model. According to row 601 blocks' statistics of the scene, we can obtain the basic scope of several main reservoir parameters. Then we can make a reasonable divide of crude oil viscosity, reservoir depth, effective thickness, permeability and oil saturation into three grades, and set up a 3^5 geological model.

2.1 The Optimization of HDNS Technology Scheme

According to the reservoir parameters of the block 601, select one group of parameters as reservoir parameters of test Wells. The reservoir parameters are shown in Table 1.

Table 1
Reservoir Parameters of Test Wells

Parameters	Number
Average effective thickness, m	5.0
Average porosity, decimal	0.3
Average permeability, $\times 10^{-3}$ μm^2	4306
Property of cruel oil（50 ℃）, mPa•s	9000
Formation temperature, ℃	28
Horizontal length, m	200
Oil saturation, decima	0.65
Reservoir buried depth, m	515

According to the dominant mechanism of HDNS, its injection patterns cover the following subjects:

① Viscosity reducer was first injected, then nitrogen was injected, and steam was injected last;

② Viscosity reducer was first injected, then steam was injected, and nitrogen was injected last;

③ Viscosity reducer was first injected, nitrogen accompanied with steam was injected in whole stage;

④ Viscosity reducer was first injected, nitrogen with steam was injected during earlier stage;

⑤ Viscosity reducer was first injected, nitrogen with steam was injected during middle stage;

⑥ Viscosity reducer was first injected, nitrogen with steam was injected during last stage.

Table 2 is the result of different injection patterns. It illustrates the periodic production rate of injection and pattern 1 is the highest, so the best HDNS injection pattern is that viscosity reducer was first injected, then nitrogen was injected, and steam was injected last.

Table 2
The Result of Different Injection Patterns

Injection patterns	Periodic production rate, t
Viscosity reducer was first injected, then nitrogen was injected, and steam was injected last	996.7
Viscosity reducer was first injected, then steam was injected, and nitrogen was injected last	723.8
Viscosity reducer was first injected, nitrogen accompanied with steam was injected in whole stage	855.9
Viscosity reducer was first injected, nitrogen with steam was injected during earlier stage;	923.6
Viscosity reducer was first injected, nitrogen with steam was injected during middle stage	867.2
Viscosity reducer was first injected, nitrogen with steam was injected during last stage	801.6

2.2 Optimization for the Injection Parameters of HDNS Technology

Through analyzing the field production in P601, the cyclic steam injection rate, the nitrogen injection rate and the oil-soluble viscosity reducer injection rate had a greater influence on production. So these three factors are identified as the optimized parameters and each parameter is designed in five levels.

Table 3
The Levels of Each Optimized Parameters

Optimized parameters	Level 1	Level 2	Level 3	Level 4	Level 5
The cyclic steam injection rate, t/m	8	9.5	11	12.5	14
The nitrogen injection rate, Nm^3/m	0	75	150	225	300
The oil-soluble viscosity reducer injection rate, t/m	0	0.05	0.1	0.15	0.2

2.3 The Results of HDNS Parameter Combination Scheme and Analysis of Its Influences

The orthogonal design (Wang *et al*., 2010) were performed to design the scheme and analysis the result. In order to describe clearly, draw a picture for averages in different levels of each three parameters.

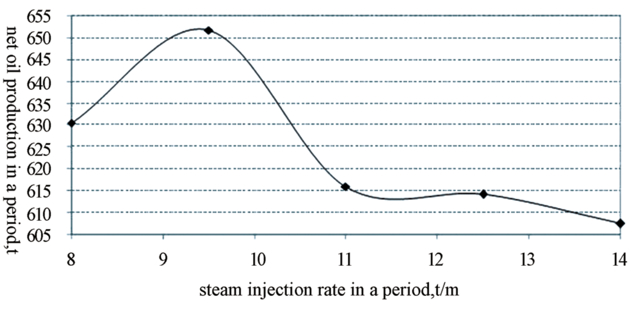

Figure 2
Averages in Different Levels of the Cyclic Steam Injection Rate

From Figure 2, it can be illustrated that net oil production drops rapidly when cyclic steam injection rate is over 10 m^3/m. So the optimal value of steam injection rate is between 9.5~10.5 m^3/m.

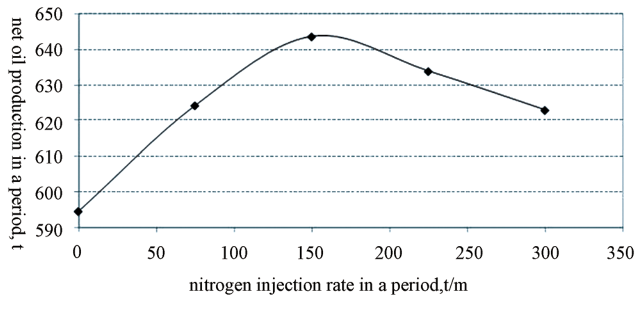

Figure 3
Averages in Different Levels of the Nitrogen Injection Rate

From Figure 3, it can be illustrated that net oil production is the highest when the nitrogen injection rate is between 140-160 Nm^3/m; so the optimal value of the nitrogen injection rate is between 140-160 Nm^3/m.

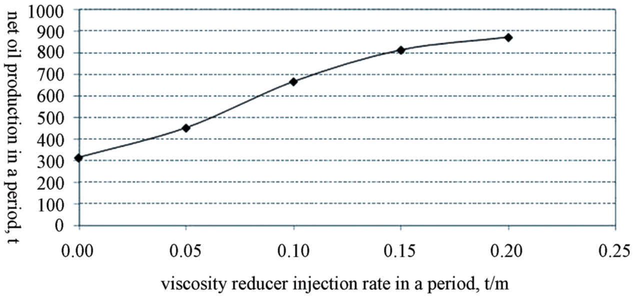

Figure 4
Averages in Different Levels of the Oil-Soluble Viscosity Reducer Injection Rate

From Figure 4, it can be illustrated that the higher viscosity reducer injection rate is, the better recovery effect is. But when the viscosity reducer injection rate reaches 0.10 t/m, the trend of Net oil production growth becomes slower. So the optimal value of the viscosity reducer injection rate is 0.10 t/m.

3. FIELD APPLICATION RESULT AND TYPICAL WELLS

HDNS is used in 68 wells on the scale required, and 379 t of average yield for one well is added. Cumulative production is added by 25772 t. Shallow super-heavy oil reservoir in Xinjiang P601 of 1020×10^4 t is effectively used by HDNS and productivity of 13×10^4 t is built. Accumulated oil production rate of Well P601-P1 reach 2666 t in the first cycle, which is an ideal result.

Table 4
Brief Description of Formation Testing for Well P601-P1 in the First Cycle

Prepose	Steam injection time	Steam injection pressure, MPa	Dryness, %	Velocity, t/h	Accumulated water injection, t
Oil-soluble viscosity reducer 20 t; Nitrogen 30000 Nm^3	2009.7.17 ~2009.7.31	10-11.2	70-71.4	8.1-10.5	3006
Commissioning date	cycle	Cycle accumulated oil production, t	Cycle accumulated water injection, t	Cycle liquid production capacity, t	Gas-oil ratio
2009.8.6	262 day	2663.3	4493	7156.3	0.89

CONCLUSION

(1) Low reservoir pressure and high viscosity of heavy oil in reservoir temperature is the main contradiction of shallow super-heavy oil reservoir. HDNS technology application significantly increased the formation pressure and the elastic energy, reduced the steam injection starting pressure, ensured that the temperature field uniform development enlarged the heating radius and drainage radius, extended the production cycle and improved the effect of thermal exploitation.

(2) Combined with P601 block reservoir geological characteristics, complete HDNS technology optimization research, adjustment should be undertaken according to single well status in the field production. During the cycle, steam, nitrogen and **viscosity reducer** injection rate should be arranged for effect of soak process.

(3) For thermal Unicom cross-well during soak process, Steam channeling management is the key point in the next step, and steam drive should be taken to improve oil recovery.

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