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Research on the Reasonable Development Technology Policy of Horizontal Well in Shallow Layer and Super Heavy Oil Reservoir

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Abstract

Horizontal well is an effective technique for developing the shallow layer and super heavy oil reservoir, and the development technology policy plays a vital role in the success or failure of the horizontal well deployment and development. According to the shallow buried depth, thin thickness, strong heterogeneity, high oil viscosity, large differences in viscosity of N_{7+8} block reservoir, according to the distribution characteristics of different viscosity, the N_{7+8} block is divided into 4 different regions of the different viscosity, the horizontal well steam development rules in the different viscosity region were researched by using numerical simulation method, the sensitivity of geological parameters, development design parameters and steam injection parameters influence the steam soak effect of horizontal well were analyzed and optimized, technical limits of key factors and reasonable design parameters, steam injection parameters were determined, which provide the decision basis for enhancing oil recovery, further infilling horizontal well and effectively transforming the development mode.

Key words: Super heavy oil reservoir; Horizontal well; Development technology policy; Steam injection parameter; Numerical simulation

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INTRODUCTION

Xinjiang oilfield has super heavy oil resources with the largest reserves in China, which account for about one third of more than 1 billion tons of super heavy oil geological reserves that have been discovered throughout the country. Super heavy oil due to its thick and easy solidification is difficult to be mined, so super heavy oil is called "couldn't flow oilfield". In the N_{7+8} block, buried depth of Qigu reservoir is shallow, ground degassed oil viscosity at 20 ℃ is 320,000 mPa·s, which is six times as much as the average low limit (50,000 mPa·s) of super heavy oil viscosity, the reservoir development difficult is very large[1-4]. How to develop this kind of reservoir becomes very important, and the horizontal well is an effective technique for developing the super heavy oil reservoir. For several years, the steam soak test of horizontal well had been carried out and had been used in the N_{7+8} block, which achieved a good development effect and effectively enhance the application confidence of horizontal well used in the super heavy oil reservoir of Xinjiang oilfield. But with the scale application of horizontal well and the extension of production time, all kinds of problematical horizontal wells are gradually increasing, which may affect the development effect of oilfield. In order to enhance oil recovery, further infill horizontal well and effectively transform the development mode, it is very necessary to study the development technology policy technique of horizontal well, which plays a vital role in the success or failure of the horizontal well deployment and development[5-13].

1. RESERVOIR CHARACTERISTICS AND THE MAIN PROBLEMS OF SUPER HEAVY OIL RESERVOIR IN THE N_{7+8} BLOCK

1.1 Reservoir Characteristics

Super heavy oil reservoir in the N_{7+8} block belongs to lithologic reservoir with layered structure, the N_{7+8} block is characterized by the highest viscosity and the shallowest buried depth in the N block, the reservoir mid-depth is -200 meters, the average reservoir thickness is 10 meters, the single thickness is thin, the marginal and bottom water is poor developed, the interlayer is more developed, the overall reservoir connectivity is good, but reservoir heterogeneity is strong. The oil bearing lithology of reservoir is chiefly mid-fine grained sandstone, followed by conglomeratic sandstone and glutenite, and loose-medium cementation. The reservoir space is mainly original intergranular pore, followed by secondary intergranular dissolved pore and intragranular pore. Porosity is 30.4%, permeability is $1,824\times10^{-3}$ μm^2, and oil saturation is 71%, which is high porosity and high permeability reservoir.

1.2 Fluid Characteristics

High viscosity and big viscosity difference of crude oil are the most distinct feature of the reservoir, the viscosity of crude oil has the characteristics of high west, low east, high north, and low south, divided into four different viscosity region (high viscosity of the N_7 region, high viscosity of the N_8 west region, medium viscosity of the N_8 north region, low viscosity of the N_8 south region). The average oil viscosity of stock tank oil in the N_8 region is 5,000 mPa·s at 50 ℃, and the average oil viscosity of stock tank oil is 25×10^4 mPa·s at 20 ℃, the average oil viscosity of stock tank oil in the N_7 region is 12,000 mPa·s at 50 ℃ and the average oil viscosity of stock tank oil is 40×10^4 mPa·s at 20 ℃, the average oil viscosity of stock tank oil in the N_{7+8} region is 8,600 mPa·s at 50 ℃ and the average oil viscosity of stock tank oil is 320,000 mPa·s at 20 ℃. Equivalent to the reservoir temperature 17.4 ℃, the stock tank oil viscosity is close to 400,000 mPa·s, the average oil density is 0.9593 g/cm^3. Seen from Figure 1, the oil viscosity is sensitive to temperature, oil viscosity will drop to about 1000 mPa·s when temperature up to 80 ℃, and the oil fluidity will greatly improve. The original reservoir temperature is 18 ℃, pressure is 1.65 MPa, and pressure coefficient is 0.99.

1.3 Main Production Problems of Reservoir

At present, the block has fifty-five horizontal wells in all, the verified reserves is 193×10^4 tons, the cumulative steam injection is 111.2×10^4 tons, the cumulative oil production is 15.8×10^4 tons, the cumulative water production is 51.7×10^4 tons, the gas-oil ratio is 0.14, thirty-six horizontal wells are opened, the monthly oil production is 781 tons that only is eight percent of the high peak value, the total average daily oil production of single well is only 0.5 tons, the composite water cut is 91%. Although the initial steam soak effect of horizontal well in the four viscosity region is good, but the oil production declines rapidly, the oil recovery rate is lower, and the degree of reserve recovery is low. With the increase of steam soak cycle, the cycle production time is prolonged, cycle oil production, daily oil production and gas-oil ratio are gradually cut down, the decline rate of average cycle oil production reaches 41%, the decline rate of daily oil production reaches 34%, reservoir plane and longitudinal producing degree is limited, the reservoir producing situation and the difference of steam soak effect in the each region are very big. Therefore, in order to further infill horizontal well and the effective transform of development mode, it is urgent need to study the development technology policy of horizontal well for the four different viscosity region.

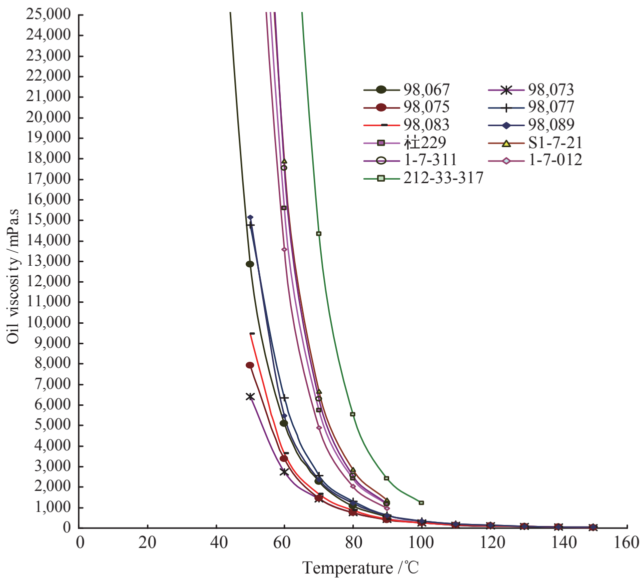

Figure 1
The Viscosity-Temperature Curve of Super Heavy Oil in the N_{7+8} Block

2. REASONABLE DEVELOPMENT TECHNOLOGY POLICY OF HORIZONTAL WELL

2.1 Single Layer Thickness

The steam soak production effects of reservoir under condition of the thickness separately is 2 m, 5 m, 8 m, 10 m, 15 m, 20 m, 25 m are simulated and compared in the N_{7+8} block. The results show that the greater reservoir thickness is, the higher oil production and gas-oil ratio is, but with the reservoir thickness is becoming thin, the oil production of horizontal well is linearly decreased, When the reservoir thickness is 5 m, the cumulative oil production has reached the oil production economic limit at 60 $. Thus, the reservoir thickness limit of horizontal well deployment is determined to 5 meters.

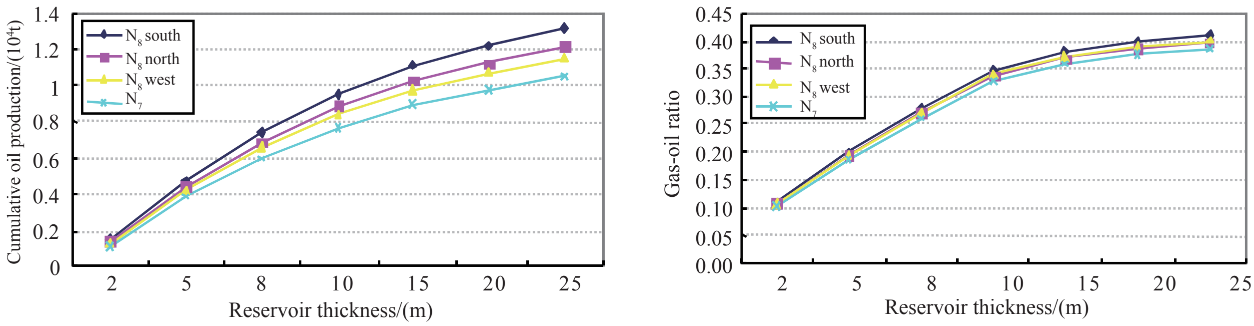

Figure 2
The Development Index Comparison Curve of Different Reservoir Thickness

2.2 Reservoir Property

According to the interpretation model of porosity and permeability, the interpretative reservoir porosity is 23%-37.5%, the average porosity is 30.4%, the permeability is 148×10^{-3}-$7,833\times10^{-3}$ μm^2, the average permeability is $1,824\times10^{-3}$ μm^2. On the plane, the porosity and the permeability in the various sublayer are closely related to sedimentary facies belts, that is the porosity and the permeability in the channel sand body is higher than that in the channel bar and flood plain. The difference of the porosity and the permeability in the longitudinal reservoir are also greater.

The steam soak development effects of horizontal well under condition of different porosity and permeability are simulated and comparatively analyzed. The results show that it has certain positive proportional relationship between permeability and cycle oil production in the initial steam soak, the higher permeability is, the higher cumulative oil production is; it also is positive proportional law between porosity and the production effect of horizontal well. From the analysis, the reservoir physical property is good, especially the horizontal well deployment layers are the high porosity and the high permeability reservoir, steam soak can achieve a better effect.

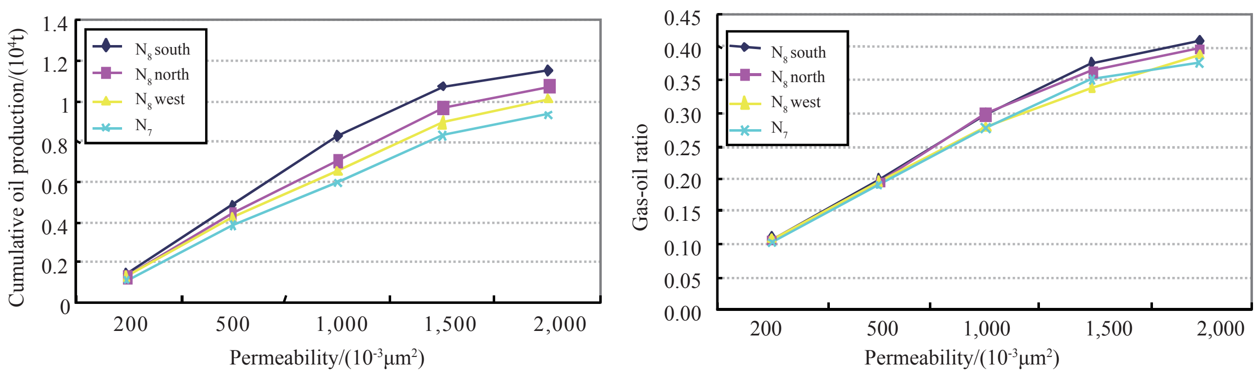

Figure 3
The Development Index Comparison Curve of Different Permeability

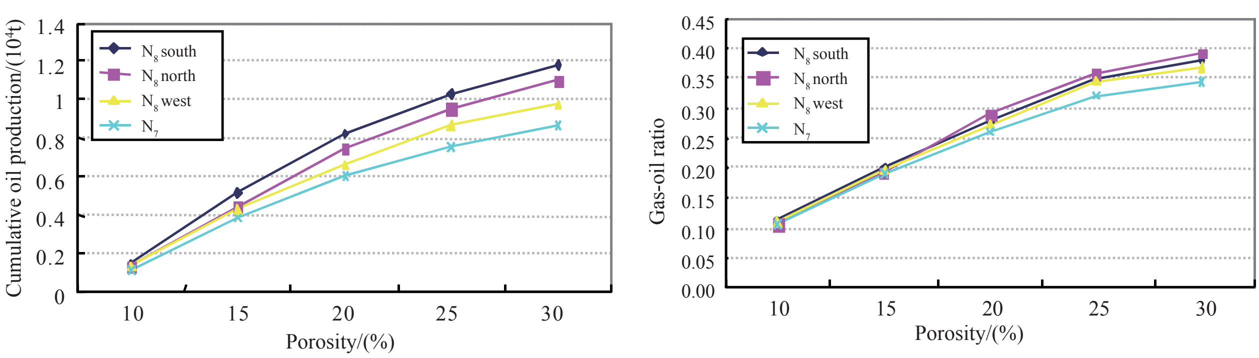

Figure 4
The Development Index Comparison Curve of Different Porosity

2.3 Vertical Position of Horizontal Section

The vertical position of horizontal well is refers to the distance from horizontal section to top or bottom boundary of reservoir, when it is optimized, the following geologic factors should be considered: Reservoir thickness and reservoir type, horizontal and vertical permeability distribution, interlayer type, size, property and property distribution law, longitudinal producing degree of reservoir. On the basis of horizontal well section drilling reservoir thickness, the steam soak development effects of horizontal well at the different distance from horizontal section to bottom boundary are simulated and optimized by using the numerical simulation methods for thermal recovery.

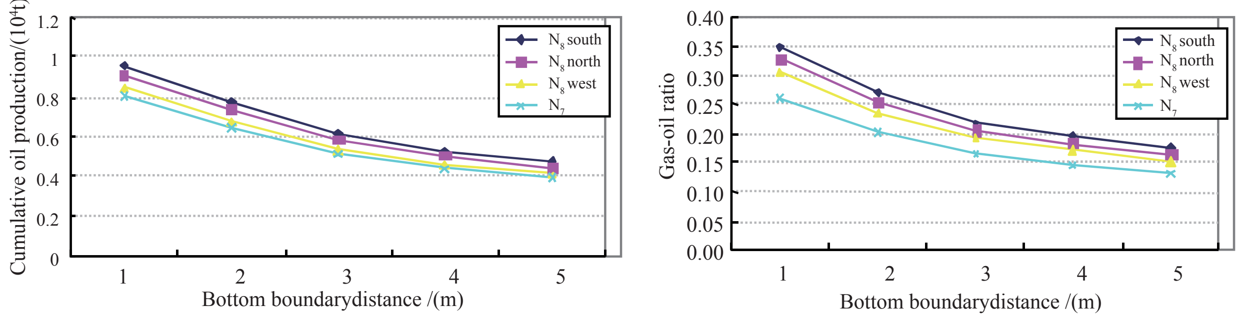

Figure 5
The Development Index Comparison Curve of Different Horizontal Section Position

Seen from Figure 5, when the vertical position of horizontal well is in the reservoir bottom boundary, the steam soak development effect of horizontal well is the best. When a horizontal well is designed in the reservoir top, the recovery effect of horizontal well will become obviously poor and cumulative oil production is lower than its economic limit because of the steam overlap. The research shows that, the steam overlap is an important factor to the exploitation of super heavy oil steam soak. It is clear that the horizontal well deployed in the bottom reservoir is easy to enhance oil recovery. But considering the heat losses to the bottom rock and drilling risk (ensure the reservoir drilling probability), it is relatively advisable for the horizontal well designed in the 1-2 meters position away from reservoir bottom.

2.4 Horizontal Section Length

Horizontal section length of horizontal well is being the design and production problem of heavy oil steam soak, if the horizontal section is short, the single control reserves and the cumulative oil production is low, which may not bring into play to the advantage of horizontal well; if the horizontal section is too long, the relatively effective length of steam injection heating becomes small, and the production economic benefit is reduced. According to the geological condition of numerical simulation region, the injection and production parameter is respectively selected, the steam soak development effects of horizontal well under the condition of different horizontal section length are simulated by using the numerical simulation method.

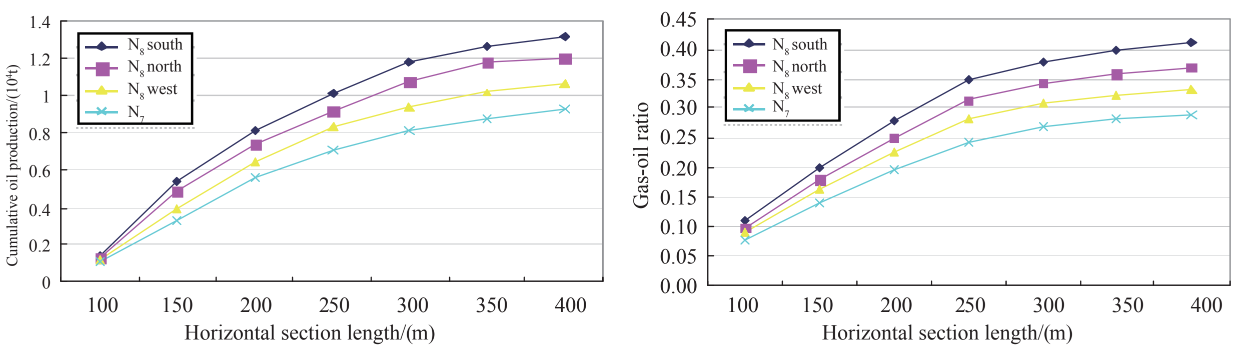

Figure 6
The Development Index Comparison Curve of Different Horizontal Section Lengths

Seen from Figure 6, the longer horizontal section is, the higher oil production of steam soak is, but the net oil production is decreased with the increasing of horizontal section length; when the horizontal section length increase to more than 350 meters, the net oil production and the gas-oil ratio rise slowly. Comprehensively analyzing the production of horizontal well, economic benefit and actual producing ability of horizontal section, the horizontal section length should be 200-250 meters.

2.5 Steam Injection Strength

The first cycle of the super heavy oil steam soak is mainly preheating and broking down the reservoir, but the heat utilization rate is low because of the interbedded reservoir heat loss is great. With the increasing of horizontal well steam injection strength, the cumulative oil production is increasing, the increase of net oil production and gas-oil ratio are larger at steam injection strength is 15-20 t/m. After the steam injection strength exceeds 25 t/m, the net oil production and the gas-oil ratio basically cannot increase, therefore, the steam injection strength should be 15-20 t/m.

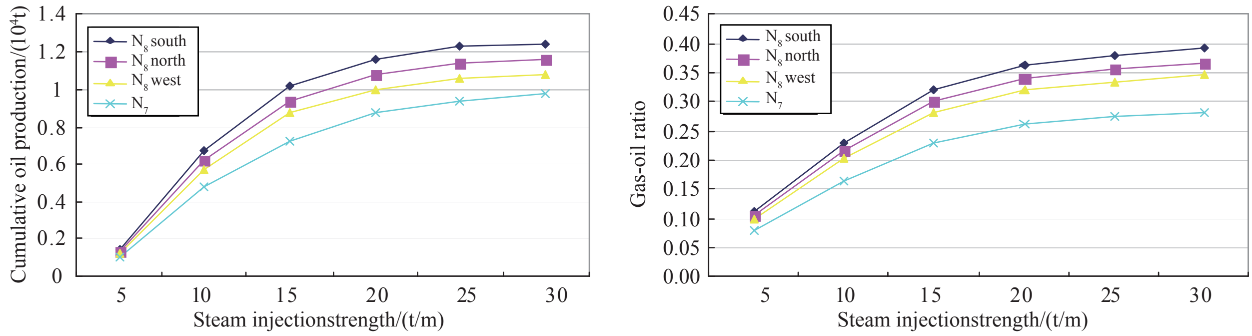

Figure 7
The Development Index Comparison Curve of Different Steam Injection Strengths

2.6 Steam Injection Rate

Under the conditions of steam injection strength is 15 t/m and the horizontal section length is 260 meters, the steam soak effect of horizontal well of different steam injection rate is simulated by using the numerical simulation method. The result in Figure 8 shows that, with the increase of steam injection rate, bottom hole steam dryness rises, in order to ensure that the bottom hole steam dryness is above 50%, the steam injection rate should be more than 150 t/d, after the steam injection rate is more than 300 t/d, the increase amplitude of bottom hole steam dryness decreases. After the steam injection rate exceeds more than 350 t/d, the cumulative oil production and the gas-oil ratio decline.

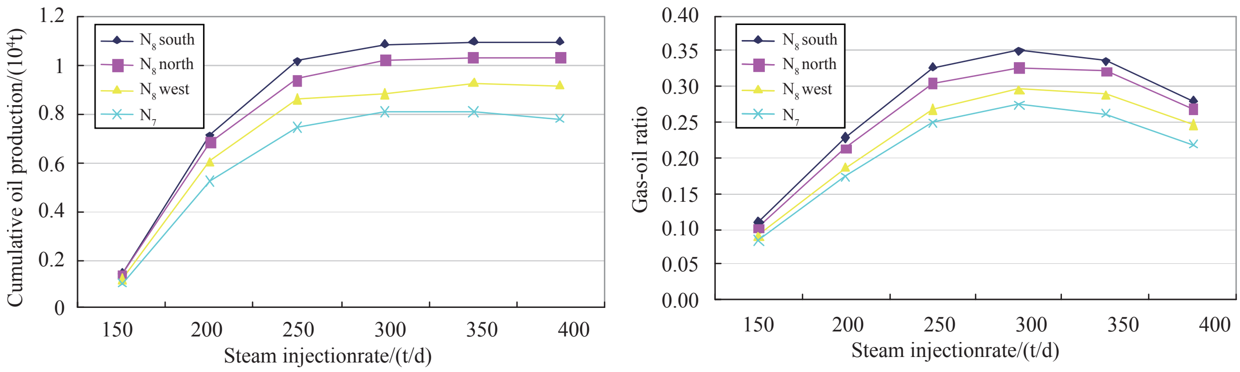

Figure 8
The Development Index Comparison Curve of Different Steam Injection Rates

After the steam enters into the reservoir, there are many factors affecting the extension of heating radius, in which the influence of steam injection rate is the most important, especially for super heavy oil. With the improving of absorbing ability of super heavy oil, the requirement for optimum steam injection rate at different steam soak stage are also different. Although the enhanced steam injection rate can reduce heat loss and improve the utilization ratio of heat, but the reservoir buried depth is shallow, the formation pressure is low, and the steam injection rate is too large, the formation is easy to break, and cause the steam channeling, combined with the actual steam injection process, the steam injection rate should be 200-250 t/d.

2.7 Steam Injection Pressure

The steam soak development effects of horizontal well under condition of different steam injection pressure are simulated and compared. Seen from Figure 9, with the increase of steam injection pressure of horizontal well, the cumulative oil production rises, after the steam injection pressure exceeds 5 MPa, the oil production and the gas-oil ratio of horizontal well decreases mainly due to the serious steam channeling because of high steam injection pressure, therefore, the optimized steam injection pressure should be 4-5 MPa.

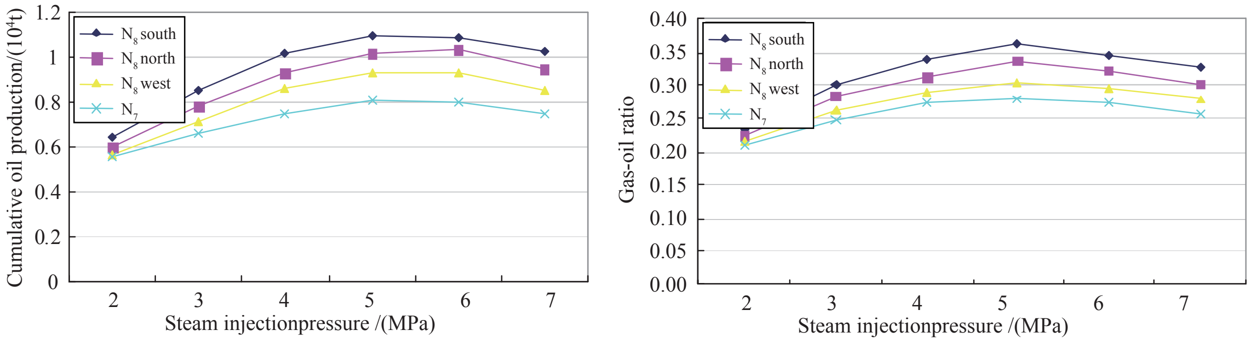

Figure 9
The Development Index Comparison Curve of Different Steam Injection Pressures

2.8 Steam Injection Temperature

The super heavy oil viscosity is sensitive to temperature, under the condition of the same amount of steam injection, the higher steam injection temperature is, the greater steam enthalpy value is, the more heat enters into the oil layer, and the steam soak effect is the better. Seen from the simulation result in Figure 10, the steam injection temperature should be higher than 200 ℃.

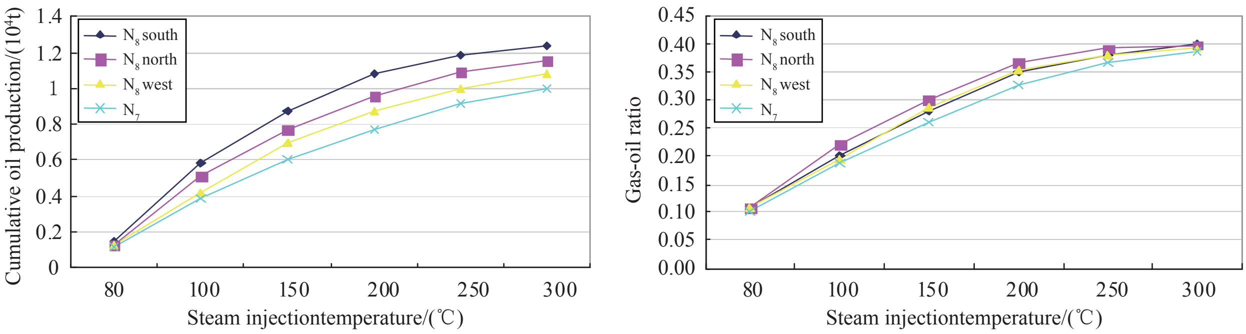

Figure 10
The Development Index Comparison Curve of Different Steam Injection Temperatures

2.9 Bottom Hole Steam Dryness

Super heavy oil viscosity is strong sensitive to temperature, therefore, the steam dryness has become one of the important technology parameters to develop super heavy oil reservoir. Under the condition of the same amount of steam injection, the higher steam injection dryness is, the greater steam enthalpy value is, the more heat enters into the oil layer, and the steam soak effect is the better. In actual operation, a low limit value of steam dryness is usually set to ensure the effect of the basic thermal recovery.

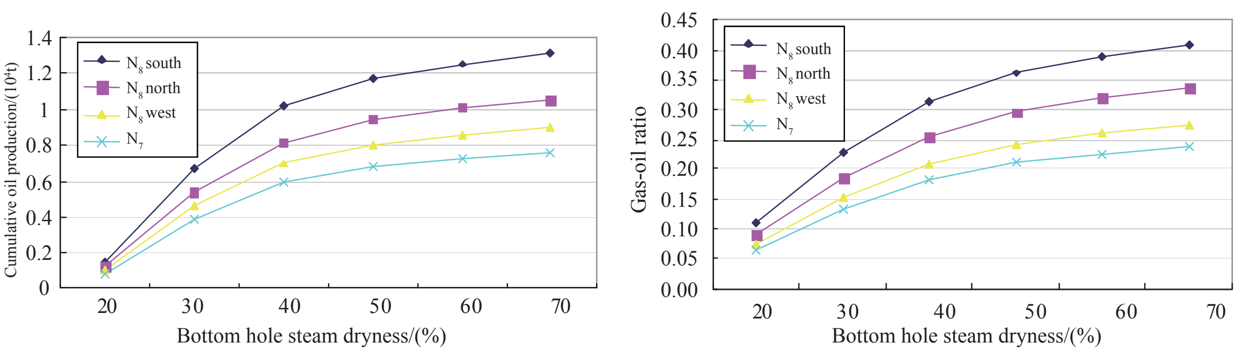

Figure 11
The Development Index Comparison Curve of Different Bottom Hole Steam Dryness

Seen from the simulation result in Figure 11, with the increasing of bottom hole steam dryness, the cumulative oil production rises. When the bottom hole steam dryness exceeds 50%, the gas-oil ratio is greater than its economic limit, and the increase amplitude of cumulative oil production decreases gradually, which indicates that enhancing the bottom hole steam dryness of horizontal well can improve the heat efficiency of oil reservoir. Therefore, in the actual production, as far as possible to improve the steam dryness to ensure the lowest bottom hole steam dryness is more than 50%.

2.10 Soak Time

When the horizontal section length is 260 meters, the bottom hole steam dryness is 50% and steam injection rate is 250 t/d, the steam soak effect of horizontal well at the soak time is 2, 3, 4, 5, 7, 10 days are simulated and compared. Seen from Figure 12, when the soak time increases from 2 to 5 days, the production effect is gradually becoming better, but when the soak time is sequentially increase, the cumulative oil production will decline. This is mainly because the soak time is too long and the heat loss is too great, resulting in the steam soak effect to become bad, the best soak time should be 4-5 days.

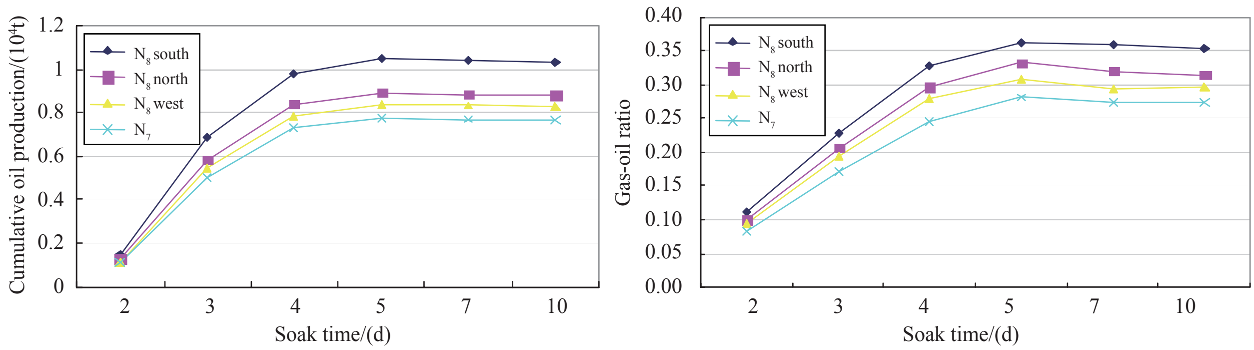

Figure 12
The Development Index Comparison Curve of Different Soak Times

The sensitivity analysis and optimization of the key factors have influence on the steam soak effect of horizontal well are carried out through the numerical simulation, reservoir engineering and steam soak seepage theory, the reasonable development technology policies of horizontal well steam soak in the N_{7+8} block are determined. The results are shown in Table 1.

Table 1
Reasonable Parameters of Steam Soak of Horizontal Well in the N_{7+8} Block

Item	Numerical value
Vertical position of horizontal section (meters)	1-2
Horizontal section length (meters)	250-300
Steam injection strength (t/m)	15-20
Steam injection rate (t/d)	200-250
Steam injection pressure (MPa)	4-5
Steam injection temperature (℃)	> 200
Bottom hole steam dryness	> 0.5
Soak time (days)	4-5

CONCLUSION

(a) High viscosity and big viscosity difference of crude oil are the most distinct feature of Qigu reservoir in the N_{7+8} block, the viscosity of crude oil has the characteristics of high west, low east, high north, and low south, according to the region distribution characteristic of oil viscosity, the N_{7+8} block is divided into four different viscosity region: high viscosity of the N_7 region, high viscosity of the N_8 west region, medium viscosity of the N_8 north region, low viscosity of the N_8 south region.

(b) The sensitivity analysis and optimization of the key factors have influence on the steam soak effect of horizontal well are carried out through the numerical simulation, reservoir engineering and steam soak seepage theory, the reasonable development technology policies of horizontal well steam soak in the N_{7+8} block are determined: The distance from horizontal section to reservoir bottom boundary is 1-2 meters, the horizontal section length is 250-300 meters, the steam injection strength is 15-20 t/m, the steam injection rate is 200-250 t/d, the steam injection pressure is 4-5 MPa, the steam injection temperature is higher than 200 ℃, the bottom hole steam dryness is more than 0.5, the soak time is 5-7 days.

(c) The reasonable development technology policy of horizontal well provides a scientific basis for improving the development effect of horizontal well, further infilling horizontal well and effectively transforming the development mode.

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