Research on optimization of development technology policy for low-permeability and low-pressure reservoir in Yangbaishan Block

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Abstract. There are poor physical properties and insufficient natural energy in the low-permeability and low-pressure reservoir of the Yangbaishan Block. Early this reservoir was mined by natural energy with a serious producing energy deficit. Subsequently, it was developed with mild water injection. During the water injection development, water quickly slid into the oil well along the crack, oil production decreased sharply and water content increased rapidly in the oil well, the water flooded well and the ineffective well gradually increased. Therefore, based on the reservoir geological characteristics, principle of injection and production balance is used to optimize reasonably for the development technology policy. Research indicates that the square inverted nine spot flooding pattern is recommended with a reasonable injection well direction of NE 72° and technical well spacing of 150 m. Reasonable injection-production ratio should be 2.16, reasonable technical well pattern density is 23 wells per square kilometer, and the average daily water injection rate of single well should be 11 m³. When injection-production system and injection proportion are improved, water drive controlled degree is expected to increase by 16 %. This research can provide reference for the efficient development and safety management of other similar reservoirs.

1 Introduction

Domestic low-permeability oil and gas resources are very rich, account for more than 2/3 of the proven oil in place, mainly distributed in the Ordos Basin, Songliao Basin, Sichuan Basin and so on. The low-permeability and ultra-low permeability oil and gas reserves increase year by year in new geological reserves. Compared with conventional reservoirs or abnormal high-pressure and low-permeability reservoirs, the geological and development characteristics of low-permeability and low-pressure reservoirs are significantly different [1]: reservoir pore and permeability is lower, fluid seepage resistance is larger, reservoir heterogeneity is stronger, oil-water differentiate is worse, water saturation is higher. If oil wells appear water breakthrough, water content will increase sharply and oil production will decrease. The natural energy of the reservoir is insufficient, oil production decreases rapidly during mining, and oil recovery is low. After the replenishment energy by water injection is effective, water content decreases, but effect cycle becomes shorter and water injection pressure increases. Therefore, this paper studies the basic factors [2-3] such as well pattern system, reasonable injection-production ratio, daily water injection rate et al, which are used to optimize water injection and effectively replenish producing energy. So safe and efficient

development mode of low-permeability and low-pressure reservoir is explored.

2 Overview of reservoir

2.1 Regional geology

The Yangbaishan Block is located in the eastern slope belt of the Ordos Basin, and has a low-amplitude nasal structural reservoir. The sedimentary type of this reservoir is delta plain subfacies, and its main oil-bearing series is the Chang 2 reservoir of the Yanchang formation in the Triassic. The lithology is thick-layered massive sandstone and thin-layered sandy mudstone. The diagenesis of the reservoir is strong. Moreover, local micro-cracks are relatively developed, resulting in that the heterogeneity of physical properties is strong in the longitudinal and lateral directions. The porosity is 8.5~19.5%, the average is 12.9%. The permeability is 0.01~49.9×10⁻³μm², the average is 26.5×10⁻³μm². The rock wettability is water wet. Formation pressure is 3.46~3.70MPa, the average is 3.56 MPa, the average saturation pressure is 0.26 MPa, and the pressure coefficient is 0.65. In summary, the reservoir in the Yangbaishan Block is a low-permeability and low-

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pressure reservoir with strong heterogeneity and controlled by lithology and physical properties.

2.2 Development characteristics

The low-permeability and low-pressure reservoir in the Yangbaishan Block have an oil-bearing area of 4.77km². A total number of wells are 121, 22 of water wells and 99 of oil wells. All production wells and injection wells was put into operation after fracturing. The cumulative liquid production is 36.25×10^4 m³, the cumulative oil production is 7.35×10^4 t, the composite water cut is 86%, the cumulative water injection is 10.27×10^4 m³, the cumulative injection-production ratio is 0.3, oil production rate is 0.11 %, and the average daily oil production of single well is 0.2 t. The reservoir was developed by natural energy in the early stage, and its producing energy was consumed in large quantities, which was subsequently converted into water injection development. At present, due to the fact that water absorption intensity of the reservoir had large difference in the water injection wells, the local producing energy could not be effectively replenished, well yield decreased rapidly, some wells were stopped production, and degree of reserve recovery is only 2.05 %.

This reservoir was put into operation after fracturing, but injection pressure of injection wells was still high and formation pressure level recovered slowly. After water breakthrough, stable production situation of oil wells was obviously worse, degree of reserve recovery and oil production rate were lower, stable production and high yield can only be achieved by maintaining or increasing formation pressure level. Through the geological characteristics re-recognition and development evaluation of the reservoir, the main problems existing are found. Partial well network and injection-production system are not perfect, producing energy supplement is insufficient, drowned wells and deficient wells are increased. In order to improve the ultimate recovery of water injection development in the reservoir, it is urgent to solve the above problems. Therefore, according to the current production history of water injection development, the research on technology policy optimization of water injection development is carried out by the reservoir engineering method.

3 Optimization of development technology policy

Aiming at the development status of low-permeability and low-pressure reservoir in Yangbaishan Block, the following measures should be taken: injection-production well pattern is improved, development of enhanced water injection and fine water injection is adopted, potential of remaining oil is tapped, reserve utilization degree and the effect of water injection development for the oilfield is improved.

3.1 Optimization of well network system

3.1.1 Well pattern

The oil layer has natural micro-cracks, serious heterogeneity, poor local development, poor connectivity and poor pressure-conducting ability. So water breakthrough direction is not obvious after waterflood. The square inverted nine spot flooding system was used in the initial stage of development, and the irregular area flooding pattern was used locally. The injector producer ratio of the inverted nine spot flooding pattern is smaller, which can increase initial production and improve water-free recovery [2, 4]. Through the water injection development, reservoir permeability is improved, and the crack is more developed than before. At this time, it is recommended that well spacing should be appropriately increased, and the row spacing needs to be reasonably reduced, that is, the rectangular inverted nine spot flooding pattern is used.

In the middle and late stages of water injection development, there are fewer response producers in this block. After the long-time water injection development, flood response efficiency of response producers is lower, but water content rises slowly and output is relatively stable. After the short-time water injection development, liquid producing capacity increases sharply. Once water injection is stopped, liquid producing capacity drops rapidly, composite water cut is over 90%. Some oil wells are flooded and stopped production; there are also some invalid wells. Due to the poor connectivity of the oil layer and the mismatch of injection and production, low liquid producing capacity still appears in the corresponding injection well. At present, according to the well pattern system, the characteristics of water injection and the change of oilfield production, specific measures for injection and production wells are specifically adjusted: infill wells and converted production wells.

3.1.2 Well alignment direction

For the development of low-permeability reservoir by water injection, the best match between well pattern system, injection-production system and fracture system must be achieved in the well network deployment, namely: "A direction of row spacing for the well is made reasonably along the crack direction". That is, the best direction of well pattern and well alignment should be parallel to the crack direction, and the waterflood direction should be perpendicular to the crack direction. Based on the anisotropy of the reservoir artificial fracture and reservoir permeability, as a whole, the natural crack and the artificial fracture in the block extend along the maximum principal stress direction NE72°. So the optimal direction of water injection wells is NE72°, That is, the direction of the well alignment is parallel to the direction of the sand body belt, and the wells in the row are staggered. At this time, the time of water breakthrough and flooding is delayed in the corner wells of the sand body direction, and the water injection effect time of the oil wells perpendicular to the sand body direction is shortened. The higher waterflood

sweep efficiency and the uniformity in the flood response of oil wells are ensured.

3.1.3 Well spacing density

Reasonable technical well pattern density is directly related to the final development of the oil field. For a longer stable production time, it is necessary to adapt to the heterogeneity of the oil layer and the connectivity of the oil sand body as much as possible, reduce the loss of reserves, enhance water injection, make the main oil layer fully effective by waterflood, improve the water drive controlled degree, and achieve the expected design of oil recovery rate and ultimate recovery.

According to oil well productivity and oil recovery rate, well pattern density is determined. The calculation formula is:

$$S = \frac{10000 NV_o}{365 Aq_o E_Y R_{NO}} \quad (1)$$

In the formula:

S —reasonable technical well pattern density, wells per square kilometer;

N —initial oil in place, 10^4t ;

V_o —oil recovery rate, %;

A —oil area, km^2 ;

q_o —average oil production per well per day, t/d ;

E_Y —current comprehensive utilization rate of oil wells, that is, ratio of the actual number of production wells to the total number of production wells, 0.61;

R_{NO} —current ratio of the number of production wells to the total number of wells, 0.82.

According to the mining conditions of the Chang 2 oil layer in the Yangbaishan Block, the relationship between single well production and the well pattern density under different oil recovery rates are analyzed (Fig.1). As well pattern density increases, the average oil production per well per day decreases. When well pattern density is the same, oil recovery rate is higher, the average oil production per well per day is higher. Analysis of the change reason in the above figure is as follows. When well pattern density is getting larger and larger, waterflood swept area in the block increased, but the channelling along the crack is prone to occur in the reservoir. When oil recovery speed increases, the total oil production increases. At present, the density of the well pattern is 17 wells per square kilometer. According to current single well production and oil recovery rate, reasonable technical well pattern density is calculated to be 23 wells per square kilometer. Therefore, it is necessary to improve the reserve controlled degree of the well network by drilling the infill wells.

Fig.1. Relationship between average oil production per well per day and well pattern density

3.1.4 Reasonable well spacing

For the deployment of the injection-production pattern [5], reasonable well spacing of the oilfield requires to meet not only the small reserve loss, the high ultimate recovery rate and the oil recovery rate, the good development effect, but also the better economic benefits.

The oil drain radius of the oil layer is determined by buildup test, and well spacing is calculated.

$$d = 0.5402 r_e \quad (2)$$

$$r_e = r_w e^{\frac{S_{FE}}{1-FE}} \quad (3)$$

In the formula:

d —well spacing, m;

r_e —oil drain radius, m;

r_w —wellbore radius, m;

S —skin factor;

FE —flow coefficient.

According to the calculation, well spacing is 120-180m and the average well spacing is 150m. According to the oil drain radius, reasonable well spacing should be 130-180m. According to reasonable technical well pattern density of 23 wells per square kilometer and the current square inverted nine spot flooding pattern, well spacing is calculated to be 200m.

Well spacing in the study area is between 100-270m. When well spacing is about 100m, the water injection effect of the oil well is fast, but the channelling is serious. When well spacing is more than 200m, the water injection effect of the oil well is slow, which indicates that well pattern is not perfect and needs to be improved through infill wells. Therefore, a reasonable well spacing should be 150m.

3.2 Determination of reasonable injection-production ratio

Since the oil reservoir in the Yangbaishan Block was put into water injection development, production data of the oil field (cumulative water injection, cumulative oil production, cumulative water production, etc.) are comprehensive and accurate. According to the injection-production relationship of the sandstone oilfield developed by water injection (the semi-logarithmic relationship curve between the cumulative water

injection and the cumulative oil production) and the characteristic of the A-type waterflood curve(the semi-logarithmic relationship curve between the cumulative water production and the cumulative oil production), it was determined by fitting that $H = 1.11$ and $G = 2.1$.

According to the relationship between injection-production ratio and water-oil ratio obtained by the above derivation [6], R_{ip} was determined at different water contents.

$$R_{ip} = \frac{GWOR^H}{B_o / \gamma_o + WOR} \quad (4)$$

In the formula:

R_{ip} -injection-production ratio, dimensionless unit;

WOR -water-oil ratio, dimensionless unit;

B_o -oil volume factor, dimensionless unit;

γ_o -ground dead oil density, t/m^3 ;

H, G -determined by empirical constants.

The crude oil property parameters are known: $B_o=1.02$, $\gamma_o=0.879$, and the corresponding R_{ip} is calculated under the different water content f_w . The current composite water cut of the study area is 86%, and reasonable injection-production ratio should be 2.16. According to the above formula, the relationship between injection-production ratio and water content was calculated and drawn (Fig.2). It can be seen from the Fig.2 that in the middle and late stages of water injection development, water content of the oil well increases, water production rate and water-oil ratio increase gradually, and the actual injection-production ratio should also increase.

Fig.2. Relationship between injection-production ratio and water content

3.3 Calculation of daily water injection rate in single well

According to the principle of the flood material balance, the average daily water injection of the injection well is calculated by the average daily oil production of the oil well:

$$q_w = R_{ip} \frac{q_o B_o}{\rho_o (1 - f_w)} / M \quad (5)$$

In the formula:

q_w -average daily water injection of the injection well, m^3/d ;

q_o -average daily oil production of the oil well, t/d ;

ρ_o -ground dead oil density 0.879 , t/m^3 ;

M -injector producer ratio, inverted nine spot flooding pattern is $1/3$;

f_w -current composite water cut of the oil well, decimal.

Based on the loss of water injection and the practice of water injection development in Yangbaishan Block, and the average daily oil production per well is 0.26 t, injection-production ratio is 1.2 - 2.5 in the initial design stage of water injection. At this time, the average daily water injection rate of single well is $8 \sim 16$ m^3 . When the current average daily oil production per well is 0.2 t, and injection-production ratio is 2.16 , the average daily water injection rate per well is 11 m^3 . At present, the average daily water injection rate of single well is 6 m^3 , the local water injection is seriously insufficient, and the producing energy deficit is very large. In the later stage of water injection, it is necessary to increase the average daily water injection rate per well and enhance water injection.

4 Optimized the water drive controlled degree

According to the situation of water injection development in Yangbaishan Block, technical policy of water injection development is optimized, and the oil wells and water wells in the development plan are adjusted (Fig.3, Fig.4): 4 re-drilled injection wells, 9 converted production wells, 10 injection wells with water injection adjusted, and 21 oil wells and water wells with reperforate. Based on the corresponding relationship between injection and production, each injection well group would be compared. The pre-adjustment water drive controlled degree was 78% , and the adjusted water drive controlled degree would be 94% , which would be increased by 16% . It shows that the corresponding relationship of the injection to production and degree of reserve recovery is greatly improved.

Fig.3. Well map of the new injection wells in the block

Fig.4. Well map of the converted production wells in the block

5 Conclusions

(1) The reservoir type of Yangbaishan Block is a low-permeability and low-pressure reservoir. Bottom water energy and elastic energy in the natural energy is insufficient. It belongs to elastic weak waterflood driven by the bottom water or edge water. It should be developed by water injection as soon as possible to ensure the replenishment of the producing energy timely.

(2) The reservoir has cracks, strong heterogeneity and high reserves abundance. There are many drowned wells and inefficient wells in the water injection development stage. The square inverted nine spot flooding pattern is used. The direction of the well alignment is NE72°, reasonable technical well spacing is 150m, and reasonable technical well pattern density is 23 wells per square kilometer. Infill wells and converted production wells are taken.

(3) In the middle and late stages of water injection development, oil production decreased, but liquid producing capacity and water production rate increased significantly, resulting in serious formation deficit. Therefore, the actual injection-production ratio and injection flow rate should be increased, water injection intensity should be strengthened, rational distribution should be improved, and producing energy should be replenished in time. According to the historical production data of water injection development, the fitting analysis was carried out to determine reasonable injection-production ratio of 2.16, and the average daily water injection rate of single well is 11 m³.

(4) Through the improvement of the flooding well network and reasonable injection allocation in the Yangbaishan Block, water drive controlled degree before and after the optimization adjustment would be increase by 16 %. So the overall utilization degree of the reservoir and the level of water injection development and the ultimate recovery would be improved. The purpose of safe and efficient production of low-permeability and low-pressure reservoir in Yangbaishan Block would be realized.

Acknowledgements

This research was financially supported by Gansu Provincial Industrial Green Low-Carbon Transformation and Upgrading Project (Project Nos. GGLD-2019-060) and Longdong University Youth Science and Innovation Fund Project (Project Nos. XYZK1906).

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