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Evaluation of the Development Effect of Oilfield Water Injection

--Development Unit of Wutonggou Formation in Shannan Oilfield Shachun 5 Block

Xi Wang

School of Xi'an Shiyou University, Shanxi 710065, China

ABSTRACT

Shannan Oilfield Shachu 5 block is a typical elastic dissolved gas-driven lithological reservoir, and the underground oil and water distribution is very complicated due to the long-term water injection and drive, and after the implementation of a large number of water injection measures, it is necessary to analyse and evaluate the effect of water-driven development in this block. Through the screening index, the evaluation of water drive development effect is carried out by adopting the water content increase rate, water drive index, water storage rate and control as the main indexes. The evaluation results show that: the main contradiction faced by the reservoir development is that the rate of water content rise is too fast, and the water drive efficiency is low; the main problems faced by the reservoir to improve the water drive effect are the large differences in the distribution of residual oil between layers and wells with low multi-directional efficiency ratio, and the difficulty of water drive excavation in each layer is increased, and so on.

KEYWORDS

Water Drive Development; Indicators; Effectiveness; Analytical Evaluation.

1. DEVELOPMENT HISTORY

In 1999, Shannan oilfield Shachu 5 well area was put into development by using 300m reverse nine-point well network, and the reservoir was fully put into water injection development at the end of 2000. Overall, it shows the trend of decreasing daily liquid and oil production and increasing water content. By the end of June 2023, there are 124 oil and water wells in Shachunan 5 well area (including 85 oil extraction wells and 36 open wells), with daily liquid production of 390m3, daily oil production of 34t, and comprehensive water content rate of 91.26%; there are 39 water injection wells, and 23 water wells are open wells, with daily water injection level of 398 m3, and the monthly injection/production ratio of 0.99. It is shown in Fig. 1, which shows the trend of water injection and water content increase.

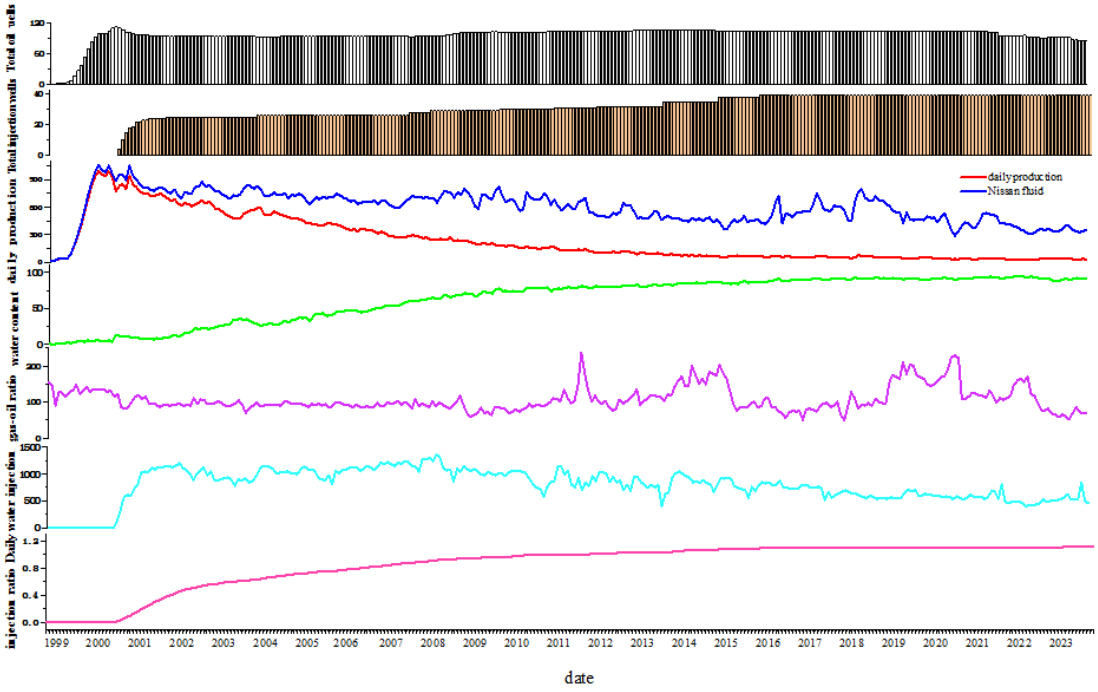

Fig. 1 Comprehensive reservoir development curve of Wutonggou Formation in Shachu 5 well area

2. DEVELOPMENT STATUS

As of March 2024, the total number of oil wells in Wutonggou Group reservoirs in Shachu 5 well area is 85, 36 wells are open, daily production is 390t of liquid, daily production is 356t of oil, water content is 91.26%, cumulative production is 220.12×104t of oil, recovery degree is 15.47%, total number of water injection wells is 39, 23 wells are open, daily water injection is 398m3, cumulative injection/production ratio is 1.12.

Table 1 Current production status of Wutonggou Formation in Shachunan Oilfield Shachun 5 Well Area

Number of oil recovery wells, pcs	85	Number of water injection wells, ports	39
Number of oil wells opened, ports	36	Number of water injection wells opened, pcs	23
Fluid production level, t/d	390	Ratio of injection and extraction wells	0.45
Oil production level, t/d	356	Daily injection level,m3	398
Cumulative oil production, t	220.12×104	Monthly injection/production ratio	0.99
Oil recovery rate, %	0.09	Cumulative injection and extraction ratio	1.12
Extraction degree, %	15.47	Water storage rate, %	55
Comprehensive water content, %	91.26	Water drive index	1.25
Degree of water drive control/%	96.8	Degree of water drive utilisation/%	80.4

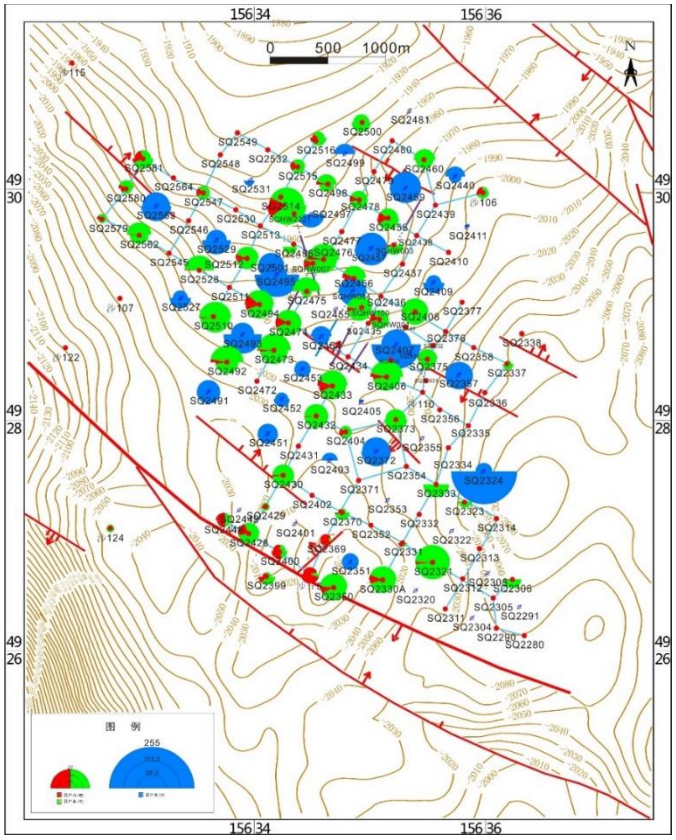

Fig. 2 Current status of the Wutonggou Formation in the Dune 5 well area

3. EVALUATION OF WATER DRIVE EFFECT

3.1. Rate of rise in water content

Oilfield water content is a comprehensive index for evaluating the development effect of oilfield, and the change rule of water content can reflect the influence of reservoir structure, non-homogeneity and underground fluid properties on the effect of water repulsion, and also reflect the reasonableness of the existing injection and extraction wells network as well as the production system. Instantaneous water content extraction ratio (dfn) is the ratio of the integrated water content at any moment to the corresponding extraction degree[1]. The formula is as follows:

$$df_n = f_{wi}/R_i \tag{1}$$

In the formula

dfn-immediate water content extraction ratio; fwi-integrated water content (%) at a certain moment; Ri-extraction degree (%) at a certain moment.

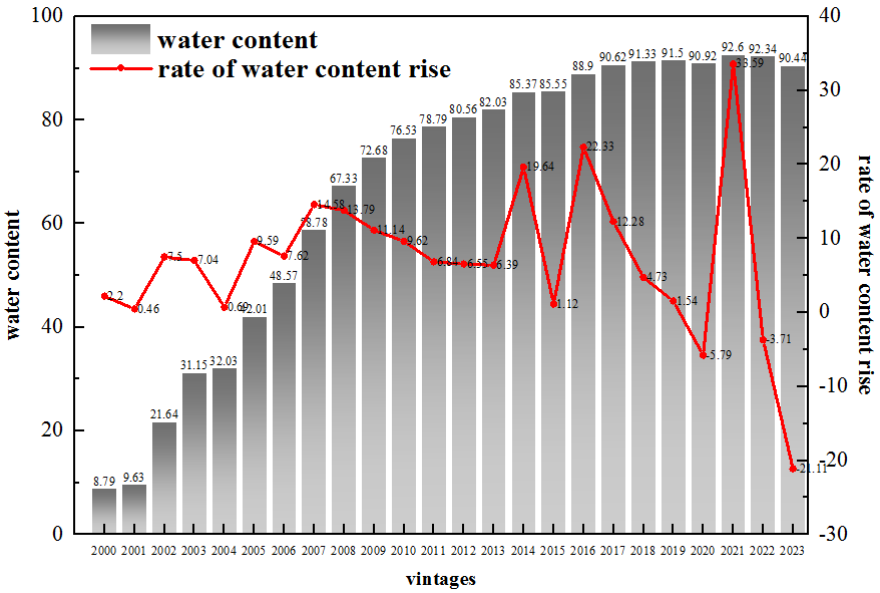

Fig. 3 Water content and water rise rate of Wutonggou Formation in Dune 5 well area

Since the development of full-scale water injection, the water content of the Wutonggou Group reservoir in the Shachu 5 well area has been on a continuous upward trend; the integrated water content rose rapidly from 9.63% to 58.78% from 2001 to 2007, and the upward trend slowed down after 2007, and the water content rate rose to 90% in 2017.

The rate of increase in water content fluctuated up and down, but there was an overall upward trend between water injection and 2007, an overall downward trend from 2007 to 2013, and an overall upward trend after 2013, with a 33.59 per cent increase in water content in 2021, when the combined water content reached 92.6 per cent, the highest in history.

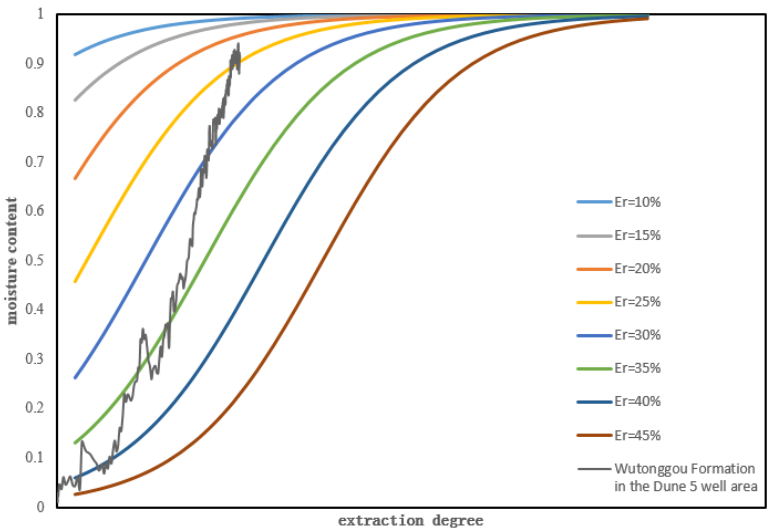

Fig.4 Curve of water content and degree of extraction in the Sycamore Formation in the Dune 5 area

Based on the production data of the Dune 5 Wutonggou formation, a plot of the reservoir's integrated water content versus the degree of recovery was made, from which it can be seen that the overall development of the reservoir is poor. The most total recovery degree is close to 16% when the water content rises to 100% as inferred from the correlation fitting between water content and recovery degree.

3.2. Water Drive Index

Water Drive Index is an important method for evaluating the utilization rate of water injection, and its theoretical calculation equation is as follows:

$$S_{PG} = (Z-1)\frac{f_W}{B_0(1-f_W)} + Z \quad (2)$$

Where: S_PG - water drive index, decimal; Z - injection and extraction ratio, unfactored; BO - conversion factor, unfactored; fw- -theoretical water content rate, decimal;

From the relation equation of water-driven index, it can be seen that corresponding to different injection and extraction ratios, different theoretical curves of the relationship between water-driven index and water content are obtained[2]. In this study, eight theoretical curves close to the block injection ratio are plotted, and it can be seen from the theoretical curve graphs that there are different patterns of the water drive index with the change of water content, when the injection ratio=1.0, the water drive index SPG=1.0, the water drive index does not change with the water content; when the injection ratio Z>1.0, the water drive index increases with the increase of water content; when the injection ratio Z<1.0 the water drive index decreases with the increase of water content. When the injection ratio Z<1.0, the water-driven index increases with the increase of water content[3].

The study area was mainly developed by natural energy in the early stage of development, and the injection water drive became one of the main supplementary energies with the increase of water injection after the development of water injection. Since the block betting, the stage injection and extraction ratio has gradually increased from 0.1 to about 1.20, compared with the theoretical plat of the actual water-driven index curve and the water storage rate curve is obviously lower, which indicates that less formation crude oil is produced by the injected water drive, i.e., the effect of water-driven is poorer. At present, the cumulative water injection in Dune 5 block is 720.68 cm3, the cumulative liquid production is 547.72 cm3, and the calculated water repulsion index is 1.25, which reflects that the utilization rate of injected water is low, and the efficiency of water injection is not high.

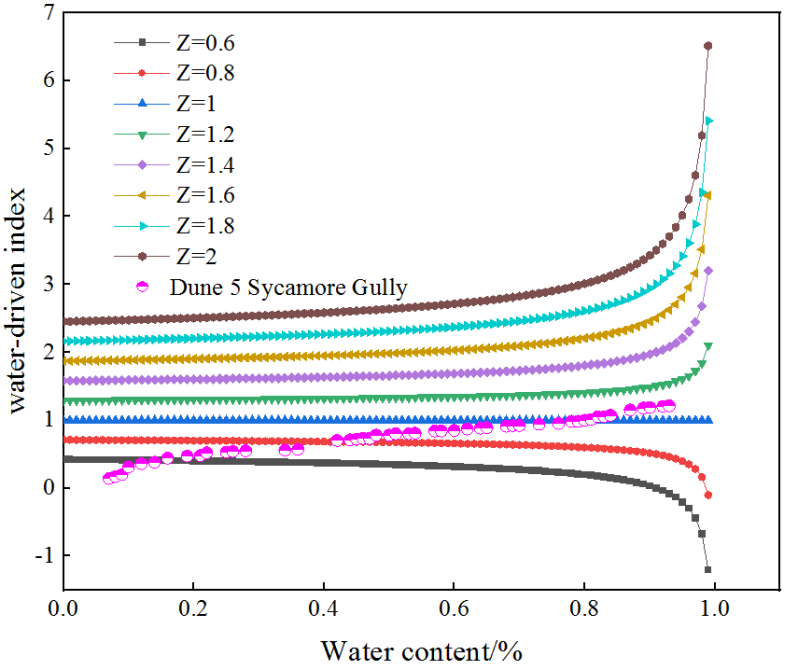

Fig. 5 Curve of water drive index and water content of Wutonggou Formation in Dune 5 well area

3.3. Water storage rate

Water storage rate is an important index used to evaluate the effect of water injection development[5]. With the gradual development of the oilfield and the increase of crude oil extraction, its comprehensive water content gradually rises. As the injected water is continuously extracted, the higher the water content is, the larger the drainage volume is, and the smaller the underground water storage rate is, the effect of stage water oil drive becomes worse[4]. Therefore, the size of underground water storage rate can be used to evaluate the development effect. According to the definition of water storage rate, the formula of actual stage water storage rate and theoretical generalized stage water storage rate are obtained.

$$c_G = \frac{\sum Q_i - \sum Q_w}{\sum Q_i} \tag{3}$$

$$C_P = 1 - \frac{1}{Z \cdot (1 + B \cdot \frac{1 - f_W}{f_W})} \tag{4}$$

Where: CG - actual stage/cumulative water storage rate, decimal; Cp - theoretical stage water storage rate, decimal; Z - generalized injection/extraction ratio, unfactored; B - conversion factor, unfactored; 1.036; fw - theoretical water content rate; Qi - stage water injection volume, 104m3; Qw - stage water production, 104m3.

By analyzing the formula and combining with the actual production of the block, this study also designs 8 theoretical water storage rate plates with different injection and extraction ratios, and obtains the theoretical curves of the relationship between the stage water storage rate and water content rate under different conditions of injection and extraction ratios (Fig.6). At the same time, the actual water storage rate curve is compared with the theoretical plate, and the results show that, in the early stage of water injection and development of Dune 5 block, due to the weak natural energy and untimely replenishment of water injection, the water storage rate is relatively low; with the development of water injection, the water storage rate increases as the injection ratio rises; at present, the stage of the injection zone has an injection ratio of 1.5, and the water storage rate is lower than the theoretical curve

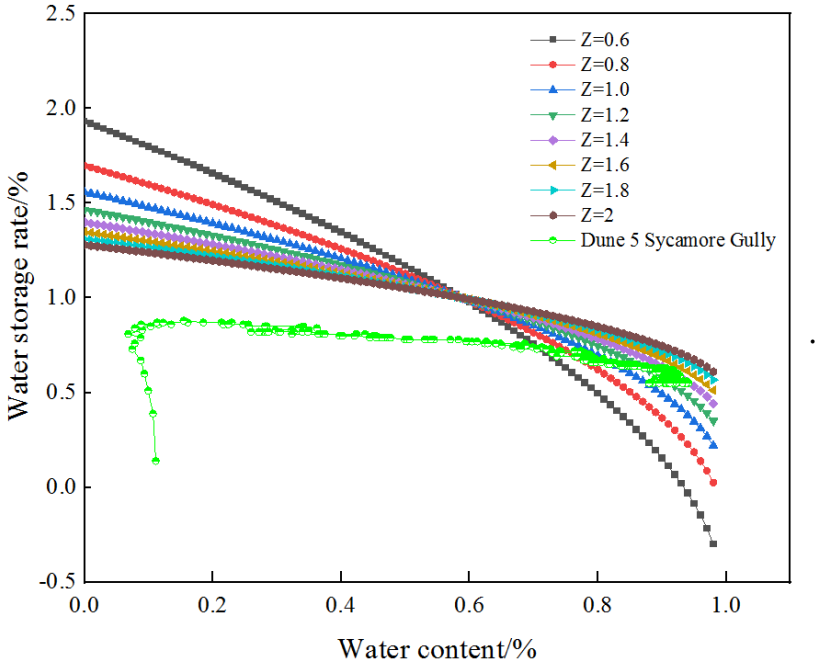

Fig. 6 Comparison of the actual water storage rate in the study area with the theoretical plate

From the changes of stages and cumulative water storage rate in the study area over the years, in the early stage of oilfield water injection development, with the injection of water, the injected water began to fill the voids in the formation and increase the formation pressure, and the water storage rate increased sharply, and the water storage rate reached the maximum in 2002, and the statistical water storage rate was 87%, and in this stage, the injection effect was good, and the production of the field was also increased accordingly. With the increase of crude oil extraction, the injected water will keep advancing to the bottom of the oil wells, resulting in the increasing of the comprehensive water content rate and the gradual decrease of the water storage rate, and the statistical water storage rate is 55% at the end of 2023, which is a low water storage rate, reflecting the low utilization rate of the injected water.

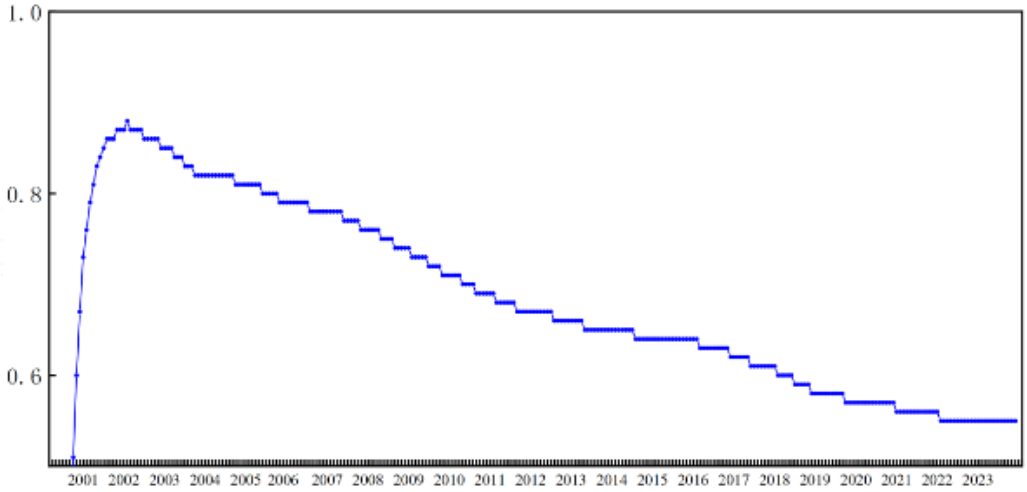

Fig. 7 Variation curve of water storage rate in the study area over the years

3.4. Ground pressure remains level

Stratigraphic energy retention level refers to whether the reservoir stratigraphic pressure maintained at a certain level is able to meet the needs of the oil extraction wells in the oilfield site for the amount of fluid extraction [6]. According to the results of various researches, the higher the reservoir

formation energy conservation level is, the higher the production differential pressure of the production wells will be, the higher the oilfield production will be, and the better the development effect will be. According to the degree of reservoir pressure maintenance and the demand of production well fluid lifting, the formation energy maintenance level can be classified into the following three categories by referring to the petroleum industry standard SY/T 6219-1996 oilfield development level grading[5].

Category 1: the formation pressure is maintained at more than 85% of the saturation pressure, which can satisfy the demand of the production wells for fluid lifting and will not cause degassing of the formation.

The second category: under this pressure, although the gas is not separated from the crude oil, but it can not meet the demand of normal production volume of oil production wells.

Category 3: The pressure not only separates the gas dissolved in the crude oil, but also fails to meet the requirement of normal production volume of oil recovery wells.

In the above three categories, when the formation energy retention level belongs to the first category, it is judged as the formation energy retention level is high; when the formation energy retention level belongs to the second category, it is judged as the formation energy retention level is medium; when the formation energy retention level belongs to the third category, it is judged as the energy retention level is poor[6].

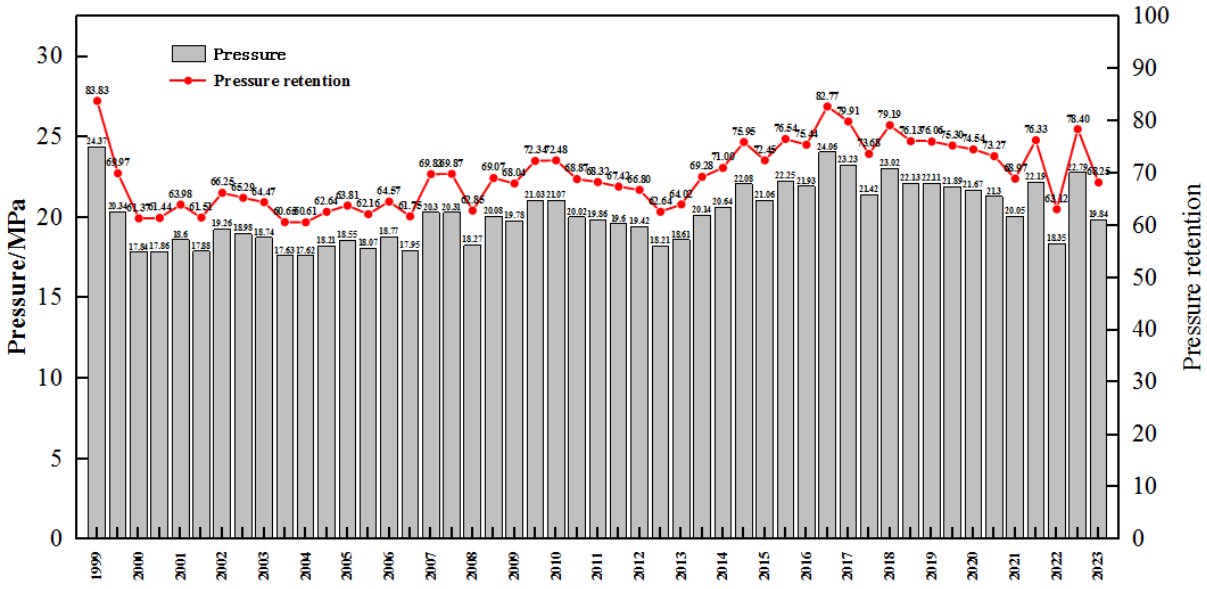

Fig. 8 Histogram of reservoir pressure changes in the Wutonggou Formation in the study area

The original stratigraphic pressure of Wutonggou Formation in Shachu 5 well area is 24.37MPa. From 1999 to 2023, the average stratigraphic pressure is maintained at about 19MPa, and the current stratigraphic pressure is 19.84MPa, and the stratigraphic saturation pressure is 14.47MPa Pressure retention rate is 81.41%, the stratigraphic pressure is higher than the saturation pressure, and the level of stratigraphic energy retention belongs to the first category, therefore, it is judged as Stratigraphic energy retention level is high.

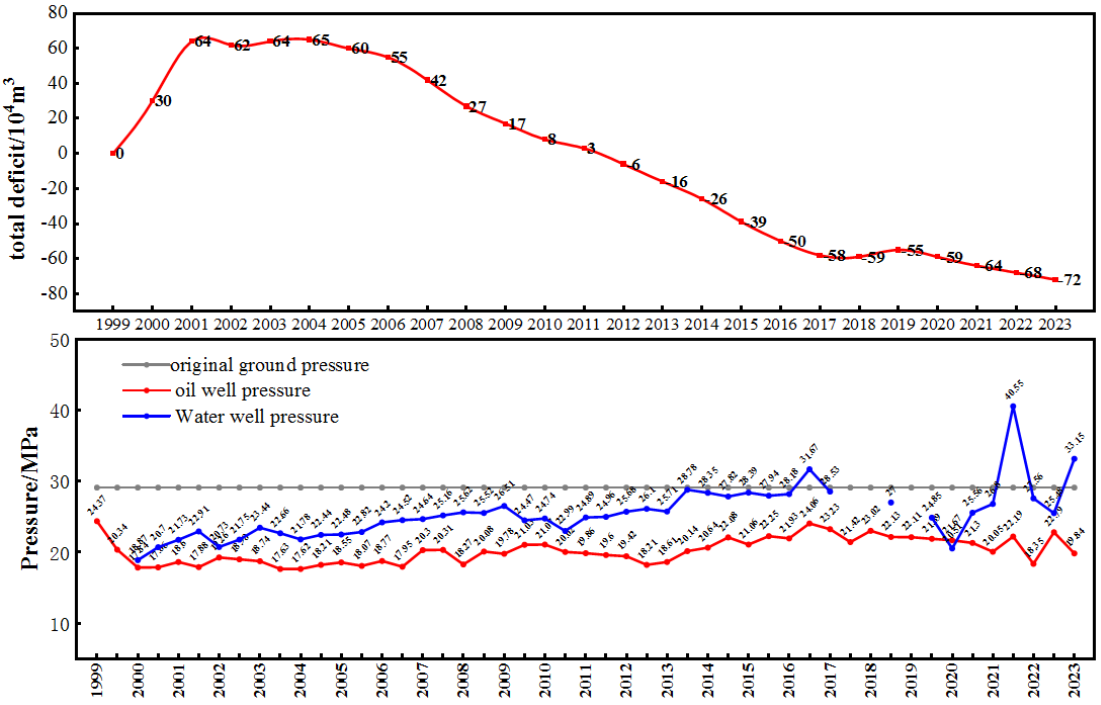

Fig. 9 Pressure variation point line diagram of Wutonggou Formation reservoir in the study area

The pressure of the wells in the initial release production of the sand dune 5 well area declined rapidly, and the degree of pressure maintenance dropped to 69.7% before the full-scale water injection and production in 2000, and after the field was put into the water injection in 2000, the trend of pressure decline slowed down, and the degree of pressure maintenance rose to 80% by 2017, but continued to decline after that, and it was difficult to recover to the original formation pressure. From development to 2003, the total formation deficit reached its peak, after which the reservoir deficit decreased year by year, and by the middle of 2012 the amount of formation deficit was completely compensated, but the formation pressure did not recover effectively.

3.5. Recovery rate prediction and evaluation

Applying A, B, C and D water-drive characteristic curves (Fig. 10 to Fig. 13), the cumulative oil production, cumulative water production and cumulative fluid production data of the Wutonggou Formation reservoirs in the Sand Dunes 5 area were processed, and the curves were inverted to predict the recoverable reserves.

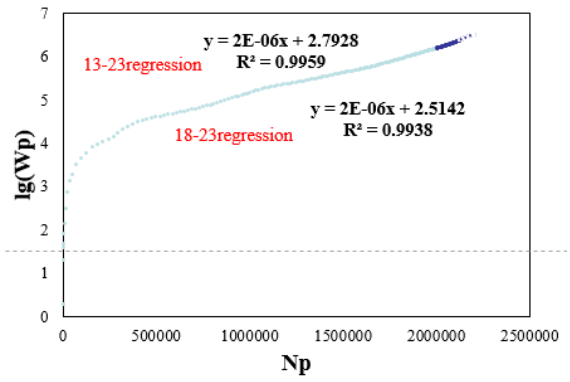

Fig.10 Dune 5 Wutonggou Formation Type A Water Drive Characterization Curve

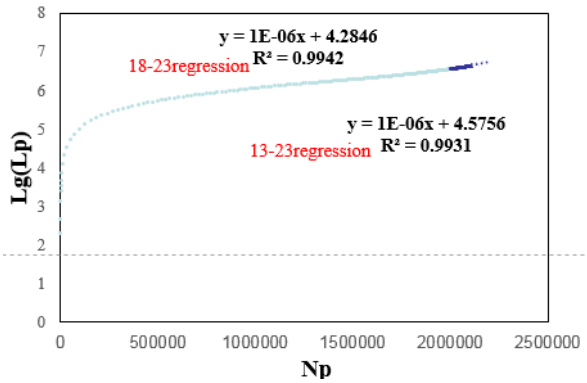

Fig.11 Dune 5 Wutonggou Formation B-type water drive characteristic curve

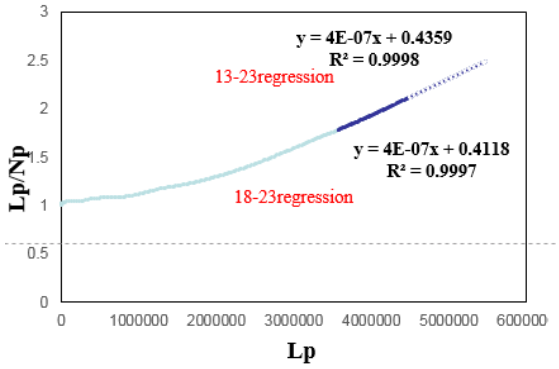

Fig.12 Dune 5 Wutonggou Formation C-type water drive characteristic curve

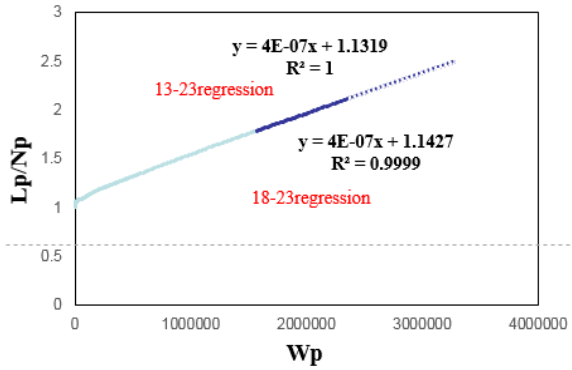

Fig.13 Dune 5 Wutonggou Formation D-type water drive characteristic curve

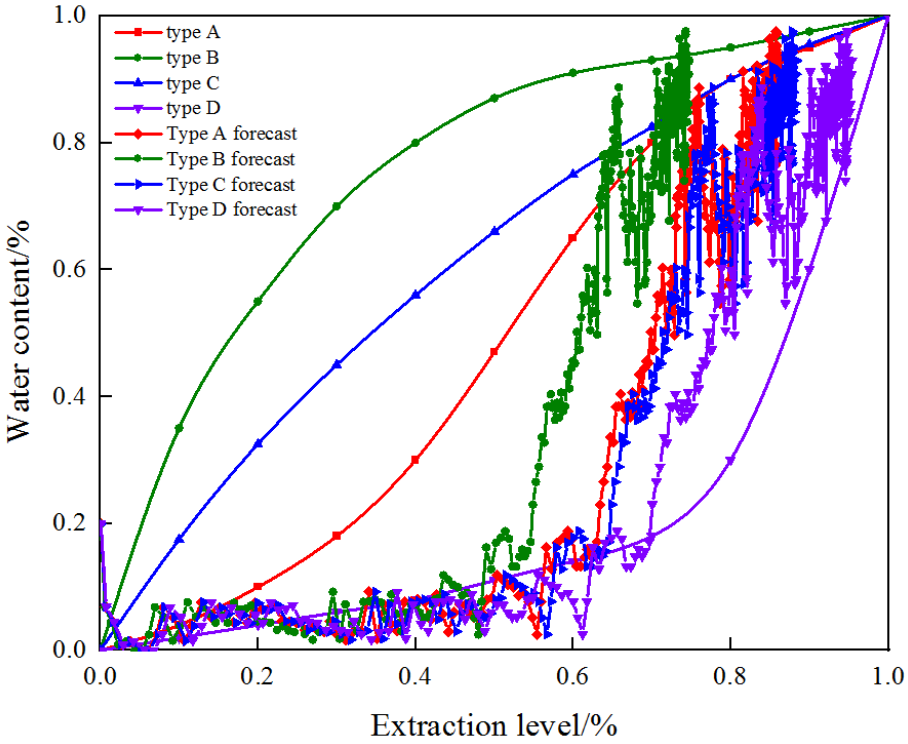

Fig 14 Curve of water content versus degree of recovery of predicted recoverable reserves and template characterizing the pattern of water content increase

The oil recovery rate of Wutonggou Formation in Shachu 5 area was predicted by the water-drive characteristic curve method and Tong's plate method, combined with the empirical formula method, and the recoverable reserves predicted by type A, B, C and D water-drive characteristic curves were 250.34×104t, 268.6×104t, 239.58×104t, and 229.95×104t, respectively.Combined with the water-bearing rate and the degree of recovery, it was considered that the water-bearing rate fitted best with the D water-drive characteristic curve as shown in the Fig. It is considered that the water content rate has the highest fit with the characteristic curve of D-type water drive as shown in the figure, and the final technical recovery rate takes the value of 17.42%, and the recoverable reserve is 229.95×104t. as shown in the table.

Table 2 Predicted recovery from the Wutonggou Formation in the Dune 5 region

Water Drive Characteristic Curve Type	Year of return	recoverable reserve	Predicted recovery (%)
type A	2018-2023	2503405.28	18.97
type B	2018-2023	2686011.43	20.34
type C	2018-2023	2395895.07	18.15
type D	2018-2023	2299556.91	17.42

4. CONCLUSION

Using the reservoir engineering method and industry evaluation standard to analyze the development index of Wutonggou group in Shannan oilfield Shachu 5 well area, it is believed that the main contradiction faced by the reservoir development is that the rate of water content rise is too fast, and the efficiency of water drive is low; the main problem faced by the reservoir to improve the effect of water drive is that the difference of residual oil distribution between the layers is large, and the ratio of the wells with multi-directional efficiency is low. Therefore, to improve the water-driven development effect of Wutonggou Group reservoirs, the main focus should be on the reorganization of the layers and the multi-directional efficiency of the oil wells.

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