A Study on rational well spacing for Producing Evaluation and Solution Scheme of the Water Injection in Northern Daqing
Blocks

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Abstract. The inter of daqing oil field has already entered the period of high water cut, with the deepening of oil and gas field development technology, the current water flooding development objects in the high and moderate permeableness layers gradually transformed into poor thin layers, such reservoirs with the complicated structure have poor development benefits, but the remaining reserves of several million tons of the demonstrated reserves mainly exist in low permeability poor thin layers. The development well pattern deployment of thin and poor pay zones still have the problems of the imperfectly injection-prodction relation, poor water flooding wells driving, and low producing degree, and it is still difficult to employ the reservoirs with poor development. In order to improve the effect of oil development, and enhance the producing degree of low poor thin reservoirs with permeability, so that it can establish the effective driving energy system, the research on effective producing limitation and technology policy limitation of thin and poor pay zones need to strengthen. Through a lot of research abroad effective producing and rational development technology policy limitation research results on the thin and poor pay zones, based on the basis of previous word, the paper study the microscopic pore structure of thin and poor layers, and compares with the thick reservoirs, while carrying out the research on effective producing limitation and development technology policy limitation of thin and poor layers. On the basis of the standard model fitting the paper analyzed the plane and vertical distribution characteristics of the remaining and also discussed the rational well spacing for producing evaluation.

1. Introduction

With the development of Daqing oilfield in the middle and later stages, some high water transition zones which are of little development value are attracting more and more attention. The data of water injection profile reflects the relative water absorption capacity of each single layer and the continuous change of water absorption in each layer under a certain pressure. The analysis of water injection profile can explain the vertical distribution and change trend of injected water in the reservoir, and provide the basis for further development of the reservoir in the later stage. In order to improve the producing degree of isotope water injection profile, the factors causing low producing degree should be analyzed, and then corresponding measures should be taken[1].

In 2019, 107 water well injection profiles of Northern-Blocks of Daqing oilfield has measured by the statistical analysis of the water drive injection profile. After classification of the effective thickness of oil layer, it can be seen from the statistical water absorption and production ratio table (Table 1),
The production ratio of water injection profile is stable between 2018 and 2019. The proportion of producing layers with effective thickness greater than 2m is 83.1%, the proportion of sandstone thickness is 81.2%, and the proportion of effective thickness is 78.4%. According to the interpretation data of sealed coring wells, the water breakthrough rate of oil layers with effective thickness greater than or equal to 2 meters is 100%, which shows that the effective thickness is greater than or equal to 2 meters. From that, when effective thickness is not lower than 2m, a lower producing will be presented.[2-3]

| Layers number | Sandstone | Effective Layers number | Sandstone | Effective | Difference(%) |
|---------------|-----------|-------------------------|-----------|-----------|---------------|
| 126           | 80.9      | 83.1                    | 81.2      | 78.4      | 1.0 1.4 0.3   |
| 107           | 77.9      | 70.9                    | 76.6      | 75.4      | 2.8 3.7 2.4   |
| 26             | 56.1      | 56.3                    | 58.9      | 57.1      | 0.3 1.6 1.0   |
| 5              | 40.6      | 38.9                    | 45.8      | 39.3      | -2.0 -1.8 -2.4|
| 13             | 31.1      | 31.5                    | 45.8      | 50.9      | 1.2 1.3 1.6   |
| 126            | 43.3      | 42.6                    | 56.3      | 64.9      | 0.5 1.0 0.5   |

2. Analysis of influencing factors of oil displacement efficiency by correlation coefficient

In probability theory and statistics, the correlation coefficient shows the strength and direction of the linear relationship between two random variables, is an index of the correlation degree between variables. Different coefficients can be used for different data. The Pearson pertinence test is the most commonly used which the covariance of two variables is divided by the standard deviation of the two variables.

$$\rho_{X,Y} = \frac{\text{cov}(X,Y)}{\sigma_x \sigma_y} = \frac{E((X-\mu_X)(Y-\mu_Y))}{\sigma_x \sigma_y}$$

When the standard deviation of two variables of mathematical characteristics is not zero, the correlation coefficient can be defined. The absolute value of the correlation coefficient is not more than 1. When the linear relationship between the two variables increases, the correlation coefficient tends to 1 or -1. For example, one variable is related to the other, the two variables are positively raised. The correlation coefficient is greater than 0. The correlation coefficient is 1, which is completely positive correlation. When the two variables are independent, the correlation coefficient is 0. But the opposite is not true, because the correlation coefficient only reflects whether the two variables are linear correlation[4-5].

The correlation between the two variables can be expressed intuitively by scatter diagram. When they are closely clustered around a straight line, the closer the absolute value of the correlation coefficient is to 1, there is a strong correlation between the variables. The points are scattered on and off the linear regression line, the absolute value of the correlation coefficient will be smaller. It is generally believed that, when the correlation coefficient is greater than 0.8, the two variables have strong linear correlation. The oil saturation of Northern-Blocks of Daqing oilfield (as shown in Fig. 1) is analyzed. The results are shown in Figure2.
According to the scatter diagram between Oil displacement efficiency and Original oil saturation, the original oil saturation has little relationship with the displacement efficiency, but the corrected oil saturation has a correlation with displacement efficiency and the correlation coefficient is large.

3. An analysis of rational well spacing

The area sweep and efficiency can be used to quantitatively describe the producing reserves. When the permeability is constant, the mathematical model between sweep efficiency and injection production well spacing and injection production pressure difference is established.

The relationship between injection production well spacing and producing reserves is discussed, then, the reasonable injection production well spacing of different well patterns in thin and poor reservoirs is determined[6-7].

From the calculation formula of area sweep and efficiency, under the same geological conditions,
the injection production pressure difference and injection production well spacing will change, which will lead to the change of area sweep efficiency. Then, the calculation of area sweep efficiency is only related to injection production pressure difference and injection production well spacing in the same oil reservoir. Using the calculated data, the three factors are analyzed by multiple regression, and a simple and convenient mathematical model for solving the area sweep efficiency is obtained.

3.1 Non-dimensional quantities
In the calculation formula of area sweep and efficiency, dimensional analysis of injection production well spacing and injection production pressure difference is needed. \( E_A \) is a dimensionless value. \( \Delta P \) is expressed in MPa. \( L \) is expressed in m. The dimensionless analysis of \( \Delta P \) and \( L \) was carried out. The dimensionless formula is used to dimensionless between injection production pressure difference and injection production well spacing, and the dimensionless injection production pressure difference and dimensionless injection production well spacing are obtained as shown in Table 2 and table3.

\[
\Delta P_d = \frac{\Delta P}{1.842 \times 10^{-3} \mu m^2
\]

\[
L_d = \frac{L}{f_w
\]

Table 2. 10×10⁻³μm² Dimensionless results

| pressure difference (dimensionless) | well spacing (dimensionless) | areal sweep efficiency |
|-----------------------------------|-------------------------------|-----------------------|
| 0.6315                            | 1213                          | 0.93351514            |
| 0.6315                            | 1296                          | 0.82363564            |
| 0.6315                            | 1238                          | 0.63546317            |
| 0.6315                            | 1423                          | 0.56683466            |
| 0.6315                            | 1498                          | 0.46312562            |
| 0.7839                            | 1553                          | 0.94833512            |
| 0.7839                            | 1631                          | 0.81463543            |
| 0.7839                            | 1679                          | 0.71656812            |
| 0.7839                            | 1732                          | 0.61525404            |
| 0.7839                            | 1831                          | 0.55685546            |
| 0.9532                            | 1736                          | 0.98127423            |
| 0.9532                            | 1891                          | 0.90456232            |
| 0.9532                            | 1986                          | 0.81335439            |
| 0.9532                            | 2016                          | 0.71615633            |
| 0.9532                            | 2183                          | 0.62489368            |
| 1.036                            | 1989                          | 0.93544252            |
| 1.036                            | 2132                          | 0.85145663            |
| 1.036                            | 2356                          | 0.81355435            |
| 1.036                            | 2416                          | 0.73516336            |
| 1.036                            | 2589                          | 0.63249823            |

3.2 Fitting mathematical model
The fitting of mathematical model is for the five point method area well pattern of infill well pattern, which the data of injection production pressure difference, injection production well spacing and area sweep efficiency were analyzed by multiple linear regression. The form of fitting function is
determined by fitting precision. The mathematical model of area sweep efficiency is established as follows:

\[ E_A = a \Delta P_D + b L_D + c \]

Based on dimensionless data as the basic data, using origin, multiple linear regression was carried out, and the linear regression coefficient of northern block was obtained as follows:

\[ a = 2.59358, \quad b = -0.00121, \quad c = 0.7108 \]

\[ R^2 = 0.9525 \]

Table 3. 10×10⁻³μm² Area sweep efficiency error results

| Pressure difference (dimensionless) | Well spacing (dimensionless) | Areal sweep efficiency | Calculating area sweep efficiency | Error (%) |
|-------------------------------------|-----------------------------|------------------------|----------------------------------|-----------|
| 0.6315                              | 1213                        | 0.9335                 | 0.8462                           | 9.3519    |
| 0.6315                              | 1296                        | 0.8236                 | 0.7358                           | 10.6605   |
| 0.6315                              | 1238                        | 0.6354                 | 0.6954                           | 9.445     |
| 0.6315                              | 1423                        | 0.5668                 | 0.6342                           | 11.91     |
| 0.7839                              | 1553                        | 0.4631                 | 0.5218                           | 12.675    |
| 0.7839                              | 1631                        | 0.8146                 | 0.7956                           | 2.3324    |
| 0.7839                              | 1679                        | 0.7165                 | 0.6454                           | 9.9232    |
| 0.7839                              | 1732                        | 0.6152                 | 0.5354                           | 12.9714   |
| 0.7839                              | 1831                        | 0.5568                 | 0.4689                           | 15.7866   |
| 0.9532                              | 1736                        | 0.9812                 | 0.9735                           | 1.7848    |
| 0.9532                              | 1891                        | 0.9045                 | 0.9001                           | 1.4865    |
| 0.9532                              | 1986                        | 0.8133                 | 0.8003                           | 1.5984    |
| 0.9532                              | 2016                        | 0.7161                 | 0.7065                           | 1.3406    |
| 0.9532                              | 2183                        | 0.6248                 | 0.6143                           | 1.6805    |
| 1.0336                              | 1989                        | 0.9354                 | 0.9153                           | 2.1488    |
| 1.0336                              | 2132                        | 0.8514                 | 0.8315                           | 2.3373    |
| 1.0336                              | 2356                        | 0.8135                 | 0.7932                           | 6.4954    |
| 1.0336                              | 2416                        | 0.7351                 | 0.7156                           | 2.6527    |
| 1.0336                              | 2589                        | 0.6324                 | 0.6298                           | 1.4126    |

It can be seen from the above calculation results that the fitting error is small, so the area sweep efficiency mathematical model is reliable. The area sweep efficiency refers to the percentage of the area swept by the injection agent in the well pattern area, and the value range is 0-1. Therefore, there is a minimum injection production well spacing and a maximum injection production well spacing under a fixed injection production pressure difference. Then, the range of injection production well spacing is calculated. At this time, the injection production well spacing range is the reasonable well spacing range that can establish effective displacement, as shown in table 4.

Table 4. Range of injection production well spacing

| Injection production pressure difference (MPa) | Minimum well spacing (m) | Maximum well spacing (m) |
|-----------------------------------------------|--------------------------|--------------------------|
| 12                                            | 110                      | 195                      |
| 13                                            | 122                      | 201                      |
| 14                                            | 131                      | 217                      |
| 15                                            | 145                      | 229                      |
| 16                                            | 156                      | 238                      |
| 17                                            | 162                      | 246                      |
| 18                                            | 179                      | 254                      |
| 19                                            | 185                      | 263                      |
4. Conclusion
Based on evaluation of data points of producing state from wells, the pilot area on Northern Blocks of Daqing oilfield is studied to establish mathematical model of influencing factors of oil displacement efficiency by correlation coefficient. The paper finds affecting factors on producing state in reservoir and ascertain major limitations on technical policy, in order to provide main measures for effective development in reservoir. On the basis of the standard model fitting the paper analyzed the plane and vertical distribution characteristics of the remaining and also discussed the rational well spacing for producing evaluation, especially carrying on the theoretical analysis to form a set of reasonable range of injection production well spacing.

Acknowledgments
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