Research on recoverable reserves of single well control in Daqing peripheral oilfield

Rui Xue
Daqing oil field exploration and development research institute. Heilongjiang Daqing, 163712, China

Abstract. This paper analyzes the law of developed single well control recoverable reserves in the Daqing peripheral oilfield through a large number of dynamic and static data of this area. Based on the influencing factors of single well control recoverable reserves, the empirical formula of exploiting Putaohua oil layer and Fuyang oil layer in Daqing peripheral oilfield was established. The formula has high precision and can meet the needs of forecasting area recoverable reserves.

Key words: single well control recoverable reserves, empirical formula, statistical regression.

1. Introduction

In oilfield development process, whether it is the development of new area or the old area adjustment, drilling new wells have a large investment, high risk characteristics, single well recoverable reserves is the basis and important indicator which determines whether the drilling has economic feasibility, so the quantitative predict of recoverable reserves in single well has the importance.

At present, the commonly used calibration method of recoverable reserves in oilfields is mainly based on the analogy and empirical formula method in new area, but the actual conditions of the well pattern and the initial development index are not taken into account. The estimated recoverable reserves error is relatively large. Water drive curve method and decline method are mainly used in old areas. Both of which require that the well have to be mined for a period of time, the feature segment of the water drive curve or the production decline curve appear. So that the recoverable reserves are often delayed for several years and cannot provide information before the decision.

The establishment of analogous reservoirs is further dependent on the recovery rate, but the results are influenced by geological reserves. So by studying the relationship between the daily production, the decreasing rate index and the recoverable reserves, the single well increase recoverable reserve forecasting model can be built which can calculate recoverable reserves of single well directly, and reduce the impact of the geologic reserve error on the calculation results.

2. The calculation method of single well recoverable reserves is clarified

Based on the analysis of single well production in the typical area of Daqing peripheral oilfield, it is found that the single well index fluctuates violently and the law is poor. It is not appropriate to calculate recoverable reserves with single well data. Therefore, the recoverable reserves of block are calculated first, then averaged to single well recoverable reserves.
Single well recoverable reserves = block recoverable reserves / block oil wells number

According to the analysis of production decline, assuming that the output decline is exponentially decreasing, the maximum cumulative oil production in the decreasing period is:

\[ N_{\text{max}} = \frac{Q_0}{D_0} \]

Where \( Q_0 \) is the initial oil production, t / d; \( D_0 \) is the initial decline rate. For wells that are in stable yield, that is the recoverable reserves of single well, it can be seen that there is a positive correlation between single well recoverable reserves and initial oil production, and a negative correlation with the initial decline rate. If we can express the relationship between \( D_0 \) and \( Q_0 \), we can find the recoverable reserves of single well.

3. The law analysis of single well Control Recoverable Reserves of developed wells in Daqing peripheral oilfield

This paper analyzes and sorts dynamic and static data of 243 blocks all the development unit in the Daqing peripheral oil field to the end of 2015. The static data includes: area, effective thickness, porosity, oil saturation, oil volume factor, ground crude oil density, crude oil geological reserve, air permeability, reservoir depth, primitive formation pressure, original saturated pressure, formation crude oil viscosity, and so on. Dynamic data includes: number of wells, number of water wells, accumulated oil, well pattern density, total water cut, and recovery percent of geological reserves. According to the principle of selecting the typical blocks, the representative blocks are selected, and the blocks are classified according to the production time and the developing oil reservoirs.

Typical block selection principle:

1. The geological reserves is relatively implemented. Through the calculation, accounting and dynamic calculation, the reserves is reasonable after the development.
2. The development data is basically reliable, with a certain scale (geological reserves of more than 200,000 tons), well pattern is basically perfect, the development way is reasonable.
3. Development time is longer (production time is generally greater than 3 years), regularity is better (with more than 12 consecutive months of steady decline trend)

Based on the analysis of the dynamic and static data of 243 blocks in Daqing Peripheral Oilfield, 66 blocks of Putuohua oil layer and 36 blocks of Fuyang oil layer are selected as the blocks of the model according to selection principle.

### Table 1. Development Blocks Elimination Reason Classification

| Elimination Reason                              | Number of units |
|------------------------------------------------|-----------------|
| Dynamic data can not be divided into reservoirs | 6               |
| Short Production time                          | 28              |
| Poor Diminishing rules                         | 53              |
| Combined oil production                        | 15              |
| Not perfect Parameter                          | 39              |
| Total                                          | 141             |

The decline curve method is used to verify the recoverable reserves of each block, so that the recoverable reserves calculation results are in line with the actual development of the oil field. At the same time, the reduction rate of the block and the initial output at the beginning of the production are calculated which can be used to fit model of single well control recoverable reserve later.
Table 2. Dynamic data table for the exploitation of Putaohua reservoir in peripheral oilfield

| Block Name | Oil wells number | Water wells number | initial daily production of single well (ton) | Decline rate (%) | Accumulate oil production of single well (ton) | Blocks recoverable reserves (Million tons) | recoverable reserves of single well control(ton) |
|------------|------------------|-------------------|-----------------------------------------------|------------------|-----------------------------------------------|------------------------------------------|----------------------------------------|
| block1     | 21               | 4                 | 3.66                                          | 18.99            | 3902.59                                       | 10.12                                    | 4048.52                                |
| block2     | 508              | 232               | 1.91                                          | 11.92            | 2056.57                                       | 225.93                                   | 3053.10                                |
| block3     | 172              | 96                | 2.46                                          | 18.53            | 1885.55                                       | 80.11                                    | 2989.15                                |
| block4     | 99               | 51                | 3.17                                          | 17.74            | 3991.06                                       | 65.44                                    | 4362.82                                |
| block5     | 26               | 13                | 2                                             | 14.63            | 3650.65                                       | 19.61                                    | 5028.00                                |
| block6     | 16               | 7                 | 2.83                                          | 12.42            | 2697.05                                       | 12.19                                    | 5297.96                                |
| block7     | 657              | 297               | 5.17                                          | 19.68            | 3593.31                                       | 403.29                                   | 4227.41                                |
| block8     | 57               | 35                | 5                                             | 9.79             | 2685.99                                       | 32.28                                    | 3508.24                                |
| block9     | 247              | 107               | 3.5                                           | 19.47            | 1781.58                                       | 97.78                                    | 3421.72                                |
| block10    | 188              | 107               | 1.67                                          | 19.23            | 3516.93                                       | 100.94                                   | 3462.82                                |
| block11    | 21               | 7                 | 5                                             | 16.03            | 2995.63                                       | 12.38                                    | 4421.89                                |
| block12    | 114              | 43                | 3.6                                           | 13.4             | 1148.94                                       | 36.95                                    | 1934.539                               |
| block13    | 148              | 43                | 4.7                                           | 8.6              | 1697.89                                       | 62.11                                    | 3357.043                               |
| block14    | 79               | 35                | 2.0                                           | 10.6             | 4669.00                                       | 60.95                                    | 5346.088                               |
| block15    | 58               | 20                | 4.3                                           | 8.5              | 3046.79                                       | 33.97                                    | 4354.949                               |
| block16    | 339              | 109               | 3.0                                           | 9.5              | 2210.53                                       | 150.58                                   | 3361.228                               |
| block17    | 89               | 36                | 2.3                                           | 9.1              | 3565.92                                       | 49.99                                    | 3999.472                               |
| block18    | 78               | 41                | 4.3                                           | 16.9             | 3663.36                                       | 49.34                                    | 4146.521                               |
| block19    | 196              | 107               | 3.7                                           | 11.8             | 4104.81                                       | 152.30                                   | 5026.304                               |
| block20    | 56               | 29                | 4.2                                           | 13.4             | 5731.60                                       | 55.04                                    | 6475.471                               |
| block21    | 61               | 29                | 3.1                                           | 10.5             | 5499.02                                       | 58.06                                    | 6450.911                               |

Through the dynamic analysis of 102 typical blocks, the average single well control of Putuohua reservoir is 4266.8 tons and 4265.6 tons of Fuyang reservoir. According to the typical block classification by the production time, after 2005 put into production the Putaohua reservoir single well control recoverable reserves are an average of 2920.9 tons, Fuyang reservoir 3049.1 tons.

Table 3. Dynamic data table for the exploitation of Fuyang reservoir in peripheral oilfield

| Block Name | Oil wells number | Water wells number | daily output of single well in early production (ton) | Decline rate (%) | Accumulate oil production of single well (ton) | Blocks recoverable reserves (Million tons) | recoverable reserves of single well control(ton) |
|------------|------------------|-------------------|------------------------------------------------------|------------------|-----------------------------------------------|------------------------------------------|----------------------------------------|
| block1     | 148              | 43                | 3.6                                                  | 13.4             | 1148.94                                       | 36.95                                    | 1934.539                                |
| block2     | 142              | 43                | 4.7                                                  | 8.6              | 1697.89                                       | 62.11                                    | 3357.043                               |
| block3     | 79               | 35                | 2.0                                                  | 10.6             | 4669.00                                       | 60.95                                    | 5346.088                               |
| block4     | 58               | 20                | 4.3                                                  | 8.5              | 3046.79                                       | 33.97                                    | 4354.949                               |
| block5     | 339              | 109               | 3.0                                                  | 9.5              | 2210.53                                       | 150.58                                   | 3361.228                               |
| block6     | 89               | 36                | 2.3                                                  | 9.1              | 3565.92                                       | 49.99                                    | 3999.472                               |
| block7     | 78               | 41                | 4.3                                                  | 16.9             | 3663.36                                       | 49.34                                    | 4146.521                               |
| block8     | 196              | 107               | 3.7                                                  | 11.8             | 4104.81                                       | 152.30                                   | 5026.304                               |
| block9     | 56               | 29                | 4.2                                                  | 13.4             | 5731.60                                       | 55.04                                    | 6475.471                               |
| block10    | 61               | 29                | 3.1                                                  | 10.5             | 5499.02                                       | 58.06                                    | 6450.911                               |

Table 4. Classification of Putaohua Oil layer by Production Time

| Reservoir | Time        | initial daily production (ton) | Decline rate (%) | initial mc (%) | Accumulate oil production of single well (ton) | Blocks recoverable reserves of single well control(ton) |
|-----------|-------------|--------------------------------|------------------|----------------|-----------------------------------------------|-----------------------------------------------|
| Putaohua  | Before 2000 | 5.85                           | 16.40            | 13.32          | 5053.51                                       | 5450.7                                        |
| Putaohua  | 2000-2005   | 3.47                           | 15.09            | 20.53          | 2903.02                                       | 4146.3                                        |
| Putaohua  | After 2005  | 2.23                           | 14.97            | 15.45          | 1879.10                                       | 2920.9                                        |
Table 5. Classification of Fuyang Oil layer by Production Time

| Reservoir | Time       | Initial daily production (ton) | Decline rate (%) | Initial mc (%) | Accumulate oil production of single well (ton) | Recoverable reserves of single well control (ton) |
|-----------|------------|-------------------------------|------------------|----------------|-----------------------------------------------|-----------------------------------------------|
| Fuyang    | Before 2000| 3.81                          | 15.75            | 13.04          | 4771.68                                       | 5384.80                                       |
| Fuyang    | 2000-2005  | 3.59                          | 12.83            | 12.83          | 2165.54                                       | 4214.89                                       |
| Fuyang    | After 2005 | 1.56                          | 19.82            | 19.82          | 1387.44                                       | 3049.09                                       |

The known remaining recoverable reserves NRR is a function associated with $D_0$ and $Q_0$. If we can express the relationship between $D_0$ and $Q_0$, we can find out the relationship between $N_{max}$ recoverable reserves and block recoverable reserves.

Known: $N_{max}=Q_0/D_0$, \hspace{1cm} Come to conclusion: $N_{RR}=Q_0/FD_0$

$N_{max}$ : remaining recoverable reserves, Million tons

$D_0$ : decline rate, %

In table 1, 66 blocks of PuTaohua reservoirs are classified according to the initial daily output. In table 2, 36 blocks of FuYang reservoirs are classified according to the initial daily output. According to the table 1 and table 2, the average decline rate of each block and the average initial daily output are calculated.

Table 6. Classification statistics between the initial daily output and the decline rate of Putaohua oil layer

| Serial number | Daily output classification (tons) | Decline rate (%) | Initial daily output (tons) |
|---------------|------------------------------------|------------------|----------------------------|
| 1             | 1-1.5                              | 13.21            | 1.21                       |
| 2             | 1.5-2                              | 12.76            | 1.90                       |
| 3             | 2-2.5                              | 14.44            | 2.32                       |
| 4             | 2.5-3                              | 13.95            | 2.74                       |
| 5             | 3-4                                | 16.87            | 3.46                       |

Table 7. Classification statistics between the initial daily output and the decline rates of Fuyang oil layer

| Serial number | Daily output classification (tons) | Decline rate (%) | Initial daily output (tons) |
|---------------|------------------------------------|------------------|----------------------------|
| 1             | 1-1.5                              | 14.54            | 1.50                       |
| 2             | 1.5-2                              | 14.22            | 2.00                       |
| 3             | 2-2.5                              | 14.07            | 2.27                       |
| 4             | 2.5-3                              | 13.93            | 2.94                       |
| 5             | 3-4                                | 14.70            | 3.60                       |

\[ N_R = N_p + N_{RR} = N_p + \frac{qT}{100D_0} \]

$N_p$ : Cumulative oil production, Million tons;

$N_{RR}$ : remaining recoverable oil; Million tons;

$q$ : Oil production of single well in early stage of production, tons;

$D_0$ : decline rate, %

$T$ : Production days of single well production, day

A prediction model of Putaohua and Fuyang reservoir was established by statistical regression method.
In the calculation formula of recoverable reserves, a prediction model of recoverable reserves of single well control for Putaohua reservoir is obtained.

\[ N_R = N_p + \frac{Q^T}{100(1.0312*Q*Q - 3.2164*Q + 15.552)} \]

 Establishment of Fuyang reservoir prediction model
In the calculation formula of recoverable reserves, a prediction model of recoverable reserves of single well control for Fuyang reservoir is obtained.

\[ N_R = N_p + \frac{Q^T}{100(0.5927*Q*Q - 3*Q + 17.764)} \]

4. Accuracy verification
Take Fang 10 (2010) block as an example. At the initial stage of production, the average single well produced 2.7 tons of oil per day. In the Putaohua oil layer, the formula of recoverable reserves is
controlled by single well, and the average recoverable reserves of single well control is 4773 tons. There are 60 oil and water wells in the block. The total recoverable reserves are 278 thousand tons. The calculated oil recovery is 16.8%, while the dynamic method is 15.3%, and the relative error is 9.8%.

Prediction model of recoverable reserves for single well control in Putaohua reservoir

\[
N_R = N_P + \frac{Q_T}{100(1.0312 \cdot Q \cdot Q - 3.2164 \cdot Q + 15.552)}
\]

Single well control of recoverable reserves in Fang 10 (2010) block

\[
N_R = \frac{2.7 \cdot 360 \cdot 0.7}{100 \cdot (1.0312 \cdot 2.7 \cdot 2.7 - 3.2164 \cdot 2.7 + 15.552)} = 0.4773
\]

Single well control of recoverable reserves in Fang 10 (2010) block

\[
N_R = 4773 \cdot 60 / 10000 = 28.6
\]

Recovery rate of Fang 10 (2010) block

\[
E_R = N_R / N \cdot 100 = 28.6 / 169.3 \cdot 100 = 16.8
\]

5. Conclusion

Use the established model to predict. In the first 1.5-2.0 tons, the Putaohua oil reservoir can control recoverable reserves of about 2900-3800 tons, and the Fuyang reservoir is about 2600-3600 tons. The prediction accuracy is relatively high and the relative error is within 10%.

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