Optimization of evaluation method for recoverable reserves of polymer flooding under the condition of optimal economic benefits

Shu Yan *
Exploration and Development Research Institute of Daqing Oilfield Co Ltd., Daqing, China

*Corresponding author e-mail: yanshu0120@petrochina.com.cn

Abstract. At present, there are two main methods to calibrate the recoverable reserves of polymer flooding (polymer consumption method and one-time calculation method), both of which have their advantages and disadvantages. Which evaluation method can better reflect the characteristics of polymer development and better economic evaluation effect is a problem to be studied. In this paper, the difference between the two evaluation methods is reflected by the change of the depletion rate of fixed assets in different evaluation methods of recoverable reserves. Through the comparative analysis of the economic evaluation results of the two different evaluation methods, the economic evaluation methods suitable for polymer flooding are selected. The results show that the evaluation results of polymer consumption method are better than that of one-off calculation method in the economic evaluation of fixed oil price and variable oil price. Under the fixed oil price, the difference of internal rate of return between the former and the latter is more than 2%. Under the condition of variable oil price, the polymer consumption method is obviously better than the one-off calculation method because of the high depreciation of initial production and the small depreciation of later production (large depreciation value in the early stage and less net value of oil and gas assets in the later stage). Through comparison, the evaluation method of polymer consumption is more practical, the evaluation result of block economic benefit is better, and more development potential can be released at the same time, which is more conducive to the promotion of polymer flooding technology.

1. Introduction
Daqing Oilfield has implemented polymer development for many years. At present, the main reservoir object has changed from the first type reservoir to the second and third type reservoirs. With the worse reservoir conditions put into the development block, the development effect of the block has gradually become worse. At present, the development of oil field takes benefit as the center, and the economic benefit evaluation of productivity block is not up to standard, so it cannot be put into oil field development. Therefore, it is necessary to perfect the economic evaluation method. It is an urgent work to select a method that can objectively evaluate the economic benefits of production blocks and release more development potential. It can ensure that the implementation of polymer flooding technology can
maintain or increase the value of reserves and assets, avoid wrong investment decisions, and provide reliable decision support for decision makers.

2. Introduction of polymer flooding in Daqing Oilfield
Daqing Oilfield is the largest oilfield in China and one of the largest in the world. In the early stage of Daqing oilfield development, polymer flooding technology has been studied to improve oil recovery. It has experienced four stages: laboratory research, pilot field test, industrial field test and industrial application. Since 1990, the main Sapu reservoir of Daqing Oilfield has gradually entered the stage of ultra-high water cut oil production. The water cut has reached more than 90%, and the water cut of some wells has reached more than 95%, but the recovery rate is not high. Daqing Oilfield has successively carried out polymer test projects for oil layers in "the west of the central area", "the first section of the north area" and "Lamadian" blocks, and has achieved obvious effect of increasing oil and reducing water. At present, the main object of oil layer is changed from the first type oil layer to the second type oil layer. Through the optimization and adjustment of polymer flooding, and guided by the "four most", the innovation project is vigorously implemented. The enhanced oil recovery of the second type oil layer is equivalent to that of the first type oil layer polymer flooding. The annual oil production of polymer flooding has accounted for a quarter of Daqing oil field, and the production has been more than 10 million tons for 14 consecutive years, which has become the key technology for the sustained and stable production of the oil field.

3. The influence of different recoverable reserves evaluation methods of polymer flooding on the depletion of oil and gas assets

3.1. Depletion of oil and gas assets
The depletion of oil and gas assets is calculated according to the production method in both domestic and international standards. The depletion of oil and gas assets is calculated according to the production method, which is enough for the mining area as a unit. The depletion rate and the depletion amount of oil and gas assets are calculated according to the parameters of proved economic recoverable reserves, production and asset value.

The calculation formula is as follows:

Depletion of well and related facilities = current output of the mining area / (proved economic recoverable reserves developed at the end of the mining area + current output of the mining area) * 100%

Compared with the average life method, which considers the proportion of fixed assets, the oil production method is widely used in the oil industry for depreciation calculation.
3.2. Calibration method of recoverable reserves in polymer flooding

The calculation of new recoverable reserves of polymer flooding in Daqing oilfield can be divided into three stages, two methods:

Table 1. Calculation method of new recoverable reserves of polymer flooding in Daqing Oilfield.

| Year       | Calculated by 120 tons of recoverable reserves increased per ton of polymer injected | In 2000 and before, the block is still calculated as 120 tons of recoverable reserves per ton of polymer injection, and in 2001 and after, the block put into production is calculated as one-time increase of recoverable reserves according to the scheme EOR value. | Calculated by two percentage points increase before 2007 and increased recoverable reserves in 2007 and later by well pattern density method and numerical simulation method |
|-----------|----------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1996~2000 |                                                                                  |                                                                                                                                                                                                 |                                                                                                                                  |
| 2001~2004 |                                                                                  |                                                                                                                                                                                                 |                                                                                                                                  |
| 2005~      | Increase recoverable reserves by one-time calculation of EOR value according to the scheme |                                                                                                                                                                                                 |                                                                                                                                  |

At present, the increase of recoverable reserves of polymer flooding in Daqing Oilfield is calculated by one-off calculation, and the increase of recoverable reserves is calculated by chewing material consumption before 2005. Both methods have been used in the calibration process of recoverable reserves, and both methods have advantages and disadvantages in the use process.

3.3. The influence of evaluation opportunity of recoverable reserves of polymer flooding on depletion

According to two different evaluation methods of recoverable reserves, the impact on economic evaluation is reflected in the annual depreciation rate. Therefore, the example of polymer flooding in Daqing Oilfield is used to verify the impact of different methods on the depreciation rate. Taking block a of Daqing Oilfield for example, there are 223 production wells and 170 injection wells. The development indexes and polymer consumption are as follows:

Table 2. Calculation method of new recoverable reserves of polymer flooding

| Time (year) | Number of oil wells | Number of wells | Annual oil production (10^4t) | Annual liquid output (10^4m^3) | Annual water injection (10^4m^3) | Polymer dosage (t) |
|------------|---------------------|-----------------|------------------------------|---------------------------------|----------------------------------|--------------------|
| 1          | 73                  | 55              | 2.71                         | 53.61                           | 75.01                            | 2427.97            |
| 2          | 220                 | 170             | 13.08                        | 326.8                           | 455.84                           | 4855.92            |
| 3          | 220                 | 170             | 17.26                        | 243.41                          | 342.73                           | 4855.92            |
| 4          | 220                 | 170             | 21.14                        | 240.87                          | 340.89                           | 4855.92            |
| 5          | 220                 | 170             | 18.47                        | 240.87                          | 339.75                           | 4855.92            |
| 6          | 220                 | 170             | 14.26                        | 240.87                          | 337.95                           | 4855.92            |
| 7          | 220                 | 170             | 11.4                         | 240.87                          | 336.73                           | 3641.94            |
| 8          | 220                 | 170             | 8.66                         | 240.87                          | 335.56                           |                    |
| 9          | 220                 | 170             | 6.85                         | 240.87                          | 334.79                           |                    |
| 10         | 220                 | 170             | 5.09                         | 215.52                          | 299.11                           |                    |
| 11         | 220                 | 170             | 3.81                         | 190.17                          | 263.63                           |                    |
| 12         | 220                 | 170             | 3.24                         | 171.15                          | 237.18                           |                    |
| 13         | 220                 | 170             | 2.76                         | 154.04                          | 213.4                            |                    |
| 14         | 220                 | 170             | 2.35                         | 138.63                          | 192                              |                    |
| 15         | 220                 | 170             | 2                            | 124.77                          | 172.75                           |                    |
| Total      | 220                 | 170             | 133.08                       | 3063.32                         | 4277.32                          | 30349.51           |
3.3.1. Fully recoverable reserves at one time. In the productivity block evaluation, it is simplified that the oil production in the evaluation period is the economic recoverable reserves, and the remaining recoverable reserves in the current year are the oil production not produced in the evaluation period, including the oil production in the current year. The remaining recoverable reserves in the first year are the total cumulative oil production, and the recoverable reserves in the last year are the last annual oil production.

Table 3. One time calculation of depreciation rate

| Time (year) | Annual oil production ($10^4$ t) | Remaining recoverable reserves ($10^4$ t) | Depreciation rate (%) |
|-------------|----------------------------------|------------------------------------------|-----------------------|
| 1           | 2.71                             | 133.08                                   | 2.04                  |
| 2           | 13.08                            | 130.37                                   | 10.03                 |
| 3           | 17.26                            | 117.29                                   | 14.72                 |
| 4           | 21.14                            | 100.03                                   | 21.13                 |
| 5           | 18.47                            | 78.89                                    | 23.41                 |
| 6           | 14.26                            | 60.42                                    | 23.60                 |
| 7           | 11.40                            | 46.16                                    | 24.70                 |
| 8           | 8.66                             | 34.76                                    | 24.91                 |
| 9           | 6.85                             | 26.10                                    | 26.25                 |
| 10          | 5.09                             | 19.25                                    | 26.44                 |
| 11          | 3.81                             | 14.16                                    | 26.91                 |
| 12          | 3.24                             | 10.35                                    | 31.30                 |
| 13          | 2.76                             | 7.11                                     | 38.82                 |
| 14          | 2.35                             | 4.35                                     | 54.02                 |
| 15          | 2.00                             | 2.00                                     | 100.00                |

3.3.2. Calculation of recoverable reserves by polymer consumption method. According to the characteristics of polymer flooding, the increased recoverable reserves of polymer flooding are divided into different years according to the polymer consumption, and the increased recoverable reserves are 0 after the polymer stops. Among them, the infill recoverable reserves of well pattern are considered as 3-5 percentage points of enhanced oil recovery. The calculation method of remaining recoverable reserves in the current year is consistent with that of fully recoverable reserves in one time. The difference is that the increase of recoverable reserves is only in the year of polymer injection, and the increase of recoverable reserves without polymer injection.

Table 4. Calculation of depreciation rate by polymer consumption method

| Time (year) | Annual oil production ($10^4$ t) | Polymer dosage (t) | New recoverable reserves ($10^4$ t) | Remaining recoverable reserves ($10^4$ t) | Depreciation rate (%) |
|-------------|----------------------------------|-------------------|------------------------------------|-----------------------------------------|-----------------------|
| 1           | 2.71                             | 2428.0            | 38.3                               | 38.3                                    | 7.08                  |
| 2           | 13.08                            | 4855.9            | 16.5                               | 52.1                                    | 25.13                 |
| 3           | 17.26                            | 4855.9            | 16.5                               | 55.5                                    | 31.12                 |
| 4           | 21.14                            | 4855.9            | 16.5                               | 54.7                                    | 38.65                 |
| 5           | 18.47                            | 4855.9            | 16.5                               | 50.0                                    | 36.91                 |
| 6           | 14.26                            | 4855.9            | 16.5                               | 48.1                                    | 29.67                 |
| 7           | 11.40                            | 3641.9            | 12.4                               | 46.2                                    | 24.70                 |
| 8           | 8.66                             |                   |                                    | 34.8                                    | 24.91                 |
| 9           | 6.85                             |                   |                                    | 26.1                                    | 26.25                 |
| 10          | 5.09                             |                   |                                    | 19.3                                    | 26.44                 |
| 11          | 3.81                             |                   |                                    | 14.2                                    | 26.91                 |
| 12          | 3.24                             |                   |                                    | 10.4                                    | 31.30                 |
| 13          | 2.76                             |                   |                                    | 7.1                                     | 38.82                 |
| 14          | 2.35                             |                   |                                    | 4.4                                     | 54.02                 |
| 15          | 2.00                             |                   |                                    | 2.0                                     | 100.00                |
3.3.3. **Comparison of two methods for calculating depreciation rate.** Comparing the depreciation rate calculated by the two methods, it can be seen from the calculation results that the depreciation rate calculated by the polymer dosage method is higher in the polymer injection stage, because the recoverable reserves calculated by the method of adding oil per ton of polymer are less than the fully recoverable reserves calculated at one time in the polymer injection stage, and the result of the calculation of the depreciation rate is higher when the annual oil production is constant. If the initial depreciation rate is large, the value of initial depreciation will be large, and the value of later depreciation will be small. Due to the decrease of oil production in later period, if the value of depreciation is reduced, the result of economic benefit evaluation will be better. After polymer injection is stopped, the remaining recoverable reserves of the two methods are the same and the annual oil production is the same. Therefore, the calculation result of annual depreciation rate after polymer injection is the same. See Figure 1 for the calculation result.

![Figure 1. Comparison of two methods for calculating depreciation rate.](image)

4. **Comparison of economic evaluation results of two methods**

Taking polymer production capacity block a as an example, the capacity construction investment is 943 million yuan, and the oil and gas operation cost adopts the actual cost incurred in the previous year. See 2017 edition of economic evaluation method for oil and gas exploration and development investment project of CNPC for evaluation method.

Two different methods for calculating depreciation of polymers are evaluated. Three fixed oil prices of $50, $70 and $90 are designed. At the same time, two variable oil price models are designed. One is a variable oil price model of $55 in the first five years, $70 in the last ten years, and $70 in the first five years, and $50 in the last ten years.

From the calculation results, the evaluation results of the method of increasing oil by ton accumulation are obviously better than that of one-off calculation, and the internal rate of return is increased by 2 percentage points. In the case of oil price rising gradually, the method of using chemical agent to calculate the increase of recoverable reserves has little change compared with one-off calculation due to the low initial oil price and large depreciation rate. However, when the oil price decreases gradually, the method of using chemical agent to calculate the increase of recoverable reserves is obviously better than the one-off evaluation result because the initial oil price is high and the depreciation is large, and the later oil price is low but the depreciation is small (the early depreciation is large, and the later oil and gas net asset value is reduced).
Table 5. Comparison of economic evaluation results of two methods

| Oil price (USD) | Fixed oil price | Changing oil prices |
|----------------|----------------|---------------------|
|                | 55             | 70                  | 90                  | 55-70     | 70-55     |
| One time evaluation results |                 |                     |                     |           |
| Financial internal rate of return (%) | -1.90 | 20.19 | 33.08 | 9.64 | 15.21 |
| Financial net present value (10^4 yuan) | -11429 | 42340 | 91937 | 10926 | 19984 |
| Investment payback period (year) | 6.00 | 4.19 | 3.52 | 5.65 | 4.19 |
| Evaluation results of polymer dosage |                 |                     |                     |           |
| Financial internal rate of return (%) | 0.13 | 22.01 | 35.35 | 10.49 | 17.42 |
| Financial net present value (10^4 yuan) | -8621 | 45267 | 94611 | 12781 | 23865 |
| Investment payback period (year) | 5.68 | 3.96 | 3.37 | 5.42 | 3.96 |
| Difference (the latter minus the former) |                 |                     |                     |           |
| Financial internal rate of return (%) | 2.03 | 1.81 | 2.26 | 0.85 | 2.21 |
| Financial net present value (10^4 yuan) | 2809 | 2927 | 2673 | 1855 | 3881 |
| Investment payback period (year) | -0.33 | -0.23 | -0.15 | -0.22 | -0.23 |

5. Conclusion
Different evaluation methods of recoverable reserves have a great impact on the evaluation of development effect. From the calculation results, the evaluation effect of oil accumulation per ton is better than that of oil accumulation per ton, and the difference of internal rate of return is about 2%.

The evaluation method of recoverable reserves per ton of oil accumulation is more practical, which can objectively evaluate the economic benefits of productivity blocks and release more development potential at the same time.

The evaluation method of recoverable reserves of the polymer can also be applied to other development methods of tertiary oil recovery.

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