A New Design Method of Gel dosage for Profile Control and Water Plugging

Hui Wu¹, Weixia Liu², Yanyue Li³, Ganggang Hou⁴, Wenyue Zhao⁴, Runwei Qiao⁴, Tongjing Liu⁴*

¹Dagang Oilfield Company, China National Petroleum Corporation, Tianjin, 300280, China
²Research Institute of Petroleum Exploration and Development, Sinopec Shengli Oilfield Company, Dongying, 257015, China
³CNOOC (China) Ltd. Tianjin, 300452, China
⁴Unconventional Petroleum Research Institute, China University of Petroleum (Beijing), Beijing 102249, China

*Corresponding author e-mail: ltjcup@cup.edu.cn

Abstract. At present, there is no quantitative calculation method of gel plugging agent for profile control and water plugging. Considering the influence of gel plugging agent entering the hyperosmotic channel on the effect radius of profile control and water plugging, and the influence of the dosage requirement for the actual reservoir water storage and flooding area, a new method for quantifying dosage calculation of gel plugging agent was put forward based on the dynamic production data. According to the average dosages of \( Q_1 \), \( Q_2 \), \( Q_3 \) calculated respectively based on the displacement radius method of well testing, the water drive method of formation water storage, and the displacement radius method of advantage channels, the dosage of blocking agent \( Q_b \) for profile control and the dosage of blocking agent \( Q_d \) for water plugging were obtained. The method can meet the actual needs of gel dosage and relieve the layer contradictions and inner contradictions effectively, which will insure the measures of profile control and water plugging achieve the expected blocking effect.

1. Introduction

Most of the old oil fields in China have the characteristics of “high water cut”. Practice has proved that effective profile control can improve water absorption and output profiles, relieve the layer contradictions and inner contradictions, and slow down the decline in main reservoirs production to improve the effect of oilfield development. The choice of the type and design of dosage of gel plugging agent has an important influence on the effect of profile control and water plugging.

According to the analysis and summary of the field experimental data, the liquid phase permeability of gel plugging agent is applicable to 2~800md, which is generally applicable to conventional sandstone reservoirs in China. Previous studies have suggested that when the one-directional turbulence channel is developed, the blocking area of the plugging agent can be approximated by the area of water flooding. However, on-site practice has proved that the sealing area...
of the gel agent is inevitably larger than that of the effective flooded area; this is more obvious when there is multi-directional turbulence in the injected water.

At present, there is no quantitative calculation method of gel plugging agent for profile control and water plugging. For high water cut oil fields with the hyperosmotic channel development and water stagnation phenomenon, the results obtained by using the existing gel plugging agent dosage design method cannot meet the requirements of the site, cannot effectively alleviate the layer and inner contradictions and achieve the desired blocking effect. Therefore, the establishment of a new calculation method of gel plugging agent for profile control and water plugging is of great practical significance for on-site guidance and water plugging operation in high water cut oil fields.

2. Plugging agent screening and applicability analysis

2.1 Plugging agent system screening principle
(1) The plugging agent must closely combine the research results of geology and reservoir engineering to make the plugging agent system suitable for low permeability reservoir characteristics;
(2) Based on the mature system, the preferred plugging system needs to be applied well in practice;
(3) Fully draw on the experience gained from low permeability and other reservoirs;
(4) The preferred system should have strong adaptability and meet the needs of individualized design.

In the specific screening of plugging agents, it is necessary to summarize the previous understanding of the reservoirs, and to comprehensively evaluate the current state of technological development and screen the plugging system.

2.2 Plugging agent type and applicability
According to the performance of the plugging system, the plugging agent can be mainly divided into five categories: resin plugging agent, jelly plugging agent, gel plugging agent, precipitation plugging agent, and dispersion plugging agent.

There are many types of plugging agents used in oil fields. There are four types of chemical systems that are relatively mature in the current technology. The order of strength is: high-strength elastomer-expanded particles, cross-linked polymer gel, flexible dispersed microgel particles, Inorganic gel coat.

According to the field experimental data analysis and application summary, the selectivity limits of different formulations are obtained, as shown in Table 1.

| polymer | Phenolic resin gel | Chrome gel | Compound gel | Granular |
|---------|-------------------|------------|--------------|----------|
| 0.2     | √                 |            |              |          |
| 2       | √                 | √          |              |          |
| 3.5     | √                 |            |              |          |
| 20      | √                 |            |              |          |
| 60      | √                 | √          |              |          |
| 200     | √                 | √          |              |          |
| 800     | √                 |            |              |          |
| 3700    | √                 | √          |              |          |

3. New method for designing plugging agent dosage
The commonly used methods for calculating the amount of plugging agent are numerical simulation method, PI index method, uniform propulsion method, water absorption index method, pressure breakthrough method, and diamond area method. According to whether it is necessary to determine the radius of profile control, the above methods can be divided into three categories: the drive radius method, the fuzzy method and the numerical simulation method.

Considering the influence of the radius of profile control and water plugging, the water storage capacity of the formation, and the flooding area of multi-directional plugging on the demand of plugging agent, the plugging agent dosage $Q_1$ based on the displacement radius method of well testing.
The amount of plugging agent used in the water drive method of formation water storage $Q_2$, the calculation method of the blocking agent dosage $Q_1$ of the multi-channel plugging method based on the parameter identification result of the turbulent flow channel. Then calculate the average amount of the plugging agent obtained by the three methods to obtain the final plugging agent design value $Q$.

1. The displacement radius method of well testing

Based on the radius of action determined by the well test testing, the plugging radius is controlled to be $2/3$ of the radius of the inner zone. Therefore, the amount of plugging agent $Q_1$ is calculated by the method of profile control and water plugging radius, and the calculation formula is:

$$Q_1 = 3.14 \beta_1 \beta_2 r^2 h \phi$$

Among them, $Q_1$ is the amount of plugging agent calculated by using the provided profile control and water plugging radius method, m$^3$; $\beta_1$ is the plugging radius correction coefficient, reference value is 0.45; $\beta_2$ is the plugging thickness correction coefficient, reference value is 0.5; $r$ is the radius of the profile control and water plugging determined by the well testing, m; $h$ is the plugging thickness, according to the value of the water absorption thickness in the water absorption profile data, the effective thickness is taken directly in the single layer, m; $\phi$ is porosity, decimal.

2. The water drive method of formation water storage

According to the analysis of several oilfield profile control and water plugging cases, based on the formation water storage within the well group, the water drive experience method is used to calculate the plugging agent dosage $Q_2$. The calculation formula is:

$$Q_2 = \beta(W_i - W_p)$$

Among them, $Q_2$ is the amount of plugging agent calculated by the provided water drive experience method, m$^3$; $\beta$ is the plugging agent dosage coefficient, $0.03$–$0.05$; $W_i$ is the cumulative water injection amount, m$^3$; $W_p$ is the cumulative water production amount, m$^3$.

3. The displacement radius method of advantage channels

This method is adopted on the premise of clarifying the situation of the dominant channel. Based on the turbulent channel parameter identification results, when the one-way water channel is developed, the plugging area of the plugging agent can be approximated by the water flooding area. However, the actual situation is that the blocking area of the blocking agent is inevitably larger than the area of the effective flooded area. Therefore, when there is a multi-directional turbulent flow in the water injection well, the flooded area is as shown in Fig. 1(a), and each channel can be represented by Fig. 1(b).

![Fig 1 The diagram of flooded area between oil & water wells and multi-directional water channeling](image)

According to the research of oilfields profile control and water plugging cases, the calculation model of the total amount of multi-directional plugging agent is established, as shown in Figure 2.
Fig 2 The design factor of multi-channel block dosage

Based on the parameter identification result of the turbulent channel, the multi-channel plugging method is used to calculate the plugging agent dosage \( Q_3 \), and the calculation formula is:

\[
Q_3 = \lambda \sum q_i
\]  

(3)

Among them, \( Q_3 \) is the amount of plugging agent calculated by using the multi-channel plugging method provided, m³; \( \lambda \) is the empirical design coefficient, dimensionless; \( q_i \) is the amount of blocking agent required in the i-th sealing direction, m³.

(4) Final gel agent dosage calculation

Calculate the average value of the plugging agent dosages \( Q_1, Q_2, \) and \( Q_3 \), and obtain the final gel conditioning and water plugging agent dosage \( Q \) required for both profile control and water plugging. The calculation formula is:

\[
Q = \begin{cases} 
\frac{Q_1 + Q_2 + Q_3}{3} & \text{(profile control)} \\
\sqrt[3]{Q_1 Q_2 Q_3} & \text{(water plugging)} 
\end{cases}
\]  

(4)

Among then, \( Q \) is the final plugging agent dosage design value, m³; \( Q_1 \) is the amount of plugging agent calculated by using the profile control and water plugging radius method provided, m³; \( Q_2 \) is the plugging agent amount calculated by using the provided water drive experience method, m³; \( Q_3 \) is the amount of plugging agent calculated using the multi-channel plugging method provided, m³.

4. Field Application

The dosage design of an old oilfield with high water cut gel agent is taken as an example.

Step 1: Test the pressure of the field test well, and then use the well test interpretation software to determine the radius of the profile control and water plugging. Since there is only one layer in the oilfield, the effective thickness is 12m and the porosity is 0.14. According to formula 1, the amount of gel profile control and water plugging agent \( Q_1 \) required for different profile control and water plugging radius is calculated, as shown in Table 2.

Table 2. The dosage requirement for different effect radius of profile control and water plugging

| effect radius of profile control and water plugging /m | Agent dosage \( Q_i \) /m³ |
|------------------------------------------------------|----------------------------|
| 10                                                   | 59                         |
| 20                                                   | 237                        |
| 30                                                   | 534                        |
| 40                                                   | 950                        |
| 50                                                   | 1484                       |
| 60                                                   | 2136                       |
| 70                                                   | 2908                       |
| 80                                                   | 3798                       |
Step 2: Combine actual production data of oil fields measure the cumulative water injection volume and cumulative water production within the field well group, and calculate formation water storage. According to formula (2), the amount of gel plugging agent \( Q_2 \) required for calculating the different formation water storage is shown in Table 3.

**Table 3. The dosage requirement for different formation water storage**

| Plugging coefficient | Cumulative water injection/m³ | Cumulative water production/m³ | Formation water storage/m³ | Plugging agent dosage/m³ |
|-----------------------|-------------------------------|-------------------------------|-----------------------------|---------------------------|
| 0.04                  | 6720                          | 1720                          | 5000                        | 200                       |
| 0.042                 | 12580                         | 2580                          | 10000                       | 420                       |
| 0.044                 | 24644                         | 4644                          | 20000                       | 880                       |
| 0.046                 | 37430                         | 7430                          | 30000                       | 1380                      |
| 0.048                 | 50898                         | 10898                         | 40000                       | 1920                      |
| 0.05                  | 66347                         | 16347                         | 50000                       | 2500                      |
| 0.052                 | 85501                         | 25501                         | 60000                       | 3120                      |
| 0.054                 | 110462                        | 40462                         | 70000                       | 3780                      |
| 0.056                 | 144739                        | 64739                         | 80000                       | 4480                      |
| 0.06                  | 221385                        | 121385                        | 100000                      | 6000                      |

Step 3: Combine the results of oil field monitoring and analysis, determine the parameters of the turbulent flow channel, and calculate the amount of multi-channel sealing gel profile control and water plugging agent \( Q_3 \) required under different empirical design coefficients. Among them, the empirical design coefficient \( \lambda \) is 1.2~5.0, and its value is based on Figure 2.

The number of sealing channeling directions is 3, and the calculation results of the required amount of the plugging agent dosage requirement for the ith direction of sealing channeling are shown in Table 4.

**Table 4. The dosage requirement for the ith direction of sealing channeling**

| Experienced design coefficient | \( q_1 \) | \( q_2 \) | \( q_3 \) | \( \Sigma q_i \) | Plugging agent dosage/m³ |
|-------------------------------|----------|----------|----------|--------------|---------------------------|
| 1.2                           | 61       | 58       | 54       | 173          | 207                       |
| 1.5                           | 175      | 154      | —        | 329          | 493                       |
| 1.8                           | 421      | 129      | —        | 550          | 990                       |
| 2.0                           | 719      | 97       | —        | 816          | 1631                      |
| 2.5                           | 823      | 62       | —        | 885          | 2213                      |
| 3.0                           | 987      | 17       | —        | 1004         | 3013                      |
| 3.5                           | 1033     | —        | —        | 1033         | 3617                      |
| 4.0                           | 1137     | —        | —        | 1137         | 4547                      |
| 4.5                           | 1135     | —        | —        | 1135         | 5108                      |
| 5.0                           | 1313     | —        | —        | 1313         | 6564                      |

Step 4: According to the average value of the dosages \( Q_1, Q_2 \) and \( Q_3 \), the final gel agent dosage \( Q \) required for the two aspects of profile control and water plugging is calculated, as shown in Table 5.

**Table 5. The final gel dosages requirement for profile control and water plugging**

| Agent dosage/m³ | Final gel dosage/m³ |
|-----------------|---------------------|
| \( Q_1 \)       | \( Q_2 \)           | \( Q_3 \) | Profile control(\( Q_4 \)) | Water plugging(\( Q_5 \)) |
| 59              | 200                 | 207      | 155               | 135                        |
| 237             | 420                 | 493      | 383               | 366                        |
| 534             | 880                 | 990      | 801               | 775                        |
| 950             | 1380                | 1631     | 1320              | 1288                       |
| 1484            | 1920                | 2213     | 1872              | 1847                       |
| 2136            | 2500                | 3013     | 2550              | 2525                       |
| 2908            | 3120                | 3617     | 3215              | 3202                       |
| 3798            | 3780                | 4547     | 4042              | 4026                       |
| 4807            | 4480                | 5108     | 4798              | 4791                       |
| 5935            | 6000                | 6564     | 6166              | 6160                       |
5. Conclusions

The design method of the gel agent provided in this paper is the first to propose a quantitative calculation method. Considering the influence of the radius of action of profile control and water plugging when gel agent entering the hyperosmotic channel, combined with the production dynamic data, the effects of actual formation water storage and multi-directional sealing flooding area on the demand for gel profile control and water plugging agent are considered.

The results of the gel agent dosage calculated by the method can meet the actual requirements of the gel agent according to the actual requirements under the conditions of profile control and water plugging, effectively alleviate the layer and inner contradictions and make profile control and water plugging measures have achieved the expected plugging effect. It has important practical significance for effectively guiding the field plugging operation in oil fields with high water cut.

Acknowledgments

This work was financially supported by National Science and Technology Major Projects (2016ZX05058003, 2017ZX05009004).

References

[1] Wang Tianhui, Jia Yunlin, Lv Guosheng, etal. The Dosage of Plugging Agent in QHD32-6 Oilfield Well[J]. Journal of Petrochemical Universities, 2015, 28(2): 58-61.
[2] Su Liangyin, Pang Peng, Da Yinpeng, etal. Usage Optimization and Field Test of Blocking Agent for Temporal-blocked Re-fracturing in Low Permeability Oilfield[J]. Fault-block Gas & Oil Field, 2014, 21(1): 114-117.
[3] Wang Shuoliang, Zhang Yuan, Dong Lie, etal. Calculation of Fracture Plugging Agent Quantity in Low Permeability Reservoir[J]. Fault-block Gas & Oil Field, 2013, 20(3): 377-379.
[4] Jiang Hanqiao, Wang Shuoliang, Zhang Yuan, etal. A New Method to Calculate Blocking Agent Volume Required for Plugging Channels in Oilfields with High Water Cut[J]. China Offshore Oil and Gas, 2013, 20(3): 377-379.
[5] Hu Aiguo, Xiong Pei, Liu Guoquan, etal. Applications of Uniform Design Method in Formulation of Weak Gel System[J]. Journal of Chemical Industry & Engineering, 2010, 31(1): 58-60.
[6] LIU Quanxi, Yao Haijing, Liu Ping, etal. Temporary Blocking Agent Dosage Calculation in Fracturing Treatment[J]. Petroleum Geology & Oilfield Development in Daqing, 2005,24(6): 58-59.
[7] Fan Wenjie, Liu Lianfu, Sun Jianguo. Determination Method of Profile Control Agent Volume for Depth Profile Control Technique[J]. Petroleum Geology & Oilfield Development in Daqing, 2002, 21(2): 59-61.