Research on Laboratory Evaluation of Coalbed Methane Reservoir Water Blocking Damage Removal in Hancheng Block

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Abstract. Owing to factors such as production system change, pump shutdown and workover, there was sudden drop in formation fluid velocity of coalbed methane well in Hancheng block, resulting in water blocking damage, the gas production plunged after the well was reopened. In order to remove the water blocking damage of coalbed methane reservoir, this paper integrated extensive survey, initially selected two nonionic surfactants (B4-B5) and three anionic surfactants (B1-B3) as the experimental subjects. The results showed that the mixed effect of B3 and B5 is the best. In order to further improve the formula system, the experimental study on the selection of auxiliaries was conducted, the results showed that under the premise of meeting environmental protection, ethanol could play a good role in reducing surface tension and defoaming, and the effect was best when the addition amount was 3%. The formula of coal seam water blocking agent PT was determined through the laboratory water-blocking evaluation experiment, and laid the foundation for the subsequent field test.

Keywords: Coalbed methane well; water blocking agent; laboratory evaluation.

1. Introduction

The Hancheng block is located in the southeastern margin of the Ordos Basin in China, and it is the medium and high-order coal-rich area in our country. There are the characteristics of higher metamorphic degree and more mature coal organic matter evolution in block coal reservoir, and the gas composition is mainly methane. By integrating comprehensive indicators such as reservoir thickness and burial depth, this block belongs to a relatively ideal coalbed methane development area, and its exploration and development potential is great. However, the coal reservoir in Hancheng block has typical characteristics of low porosity, low permeability and low homogeneity, and its mechanical strength is relatively low, which makes development difficult. Affected by the production system change, pump shutdown and workover, the formation fluid velocity often changes dramatically, practice has shown that in the development process of coalbed methane, the water phase saturation near the well area increases under the condition of low flow velocity, it will damage the relative permeability of the gas phase and cause water blocking damage [1-3]. After the water blocking damage occurred, methane gas was difficult to discharge and remained in the seepage channel, the macroscopic performance was that the gas production decreased or even the gas well was out of production, it had a great impact on the
development of coalbed methane, this phenomenon had already occurred in some coalbed methane development wells in the Hancheng block.

At present, the injection of surfactant solution slowed the water blocking damage near the well zone, which had been successfully applied in some oil and gas fields [4-6], but this method was rarely mentioned in the development process of coalbed methane. Therefore, developing water blocking agents suitable for coalbed methane reservoirs is beneficial practice to remove the water blocking damage of such reservoirs.

2. Screening of Surfactants
According to the characteristics of coalbed methane reservoirs, cationic surfactants and organic amine surfactants that are easy to chemically react with the coal surface; and high polymer surfactants that are easy to block micro-pore are not suitable for use. In order to achieve the purpose of easy injection into the coal seam and the removal of water lock damage, two kinds of nonionic surfactants (B4-B5) and three kinds of anionic surfactants (B1-B3) were selected as experimental subjects, their basic properties are shown in Table.1:

| number | basic performance |
|--------|-------------------|
| B1     | easily dissolved in water, acid and alkali resistant, thermal stability, good foaming, washing, emulsification and dispersion, etc., can be mixed with non-ionic surfactants without affecting the original performance |
| B2     | excellent penetration, wetting, emulsification, diffusion and foaming properties, acid and alkali resistant, hard water and inorganic salts, etc. |
| B3     | fast and uniform penetration, good wetting, penetration, emulsification, foaming, etc. |
| B4     | good stability, strong acid and alkali resistant, hypochlorite salts, hard water and metal salt resistant, etc. |
| B5     | dissolved in water with various hardness, acid and alkali resistant, good leveling, emulsification, wetting, diffusion, etc. |

2.1. Determination of surface tension
The DT-102A automatic interfacial tension meter was used to determine the surface tension of five surfactants at different concentrations, the test results are shown in Fig.1 (multiple determinations take average):

![Fig.1 Determination results of surface tension at different concentrations of surfactant solutions](image-url)
As can be seen from Fig.1, under the low concentration state of surfactant solution, its surface tension is basically trending downward with the increase of concentration, the tension surface which B3 (anionic surfactant) and B5 (nonionic surfactant) reduce is particularly prominent.

2.2. Determination of contact angle

The interface parameter integrated measurement system was used to determine the contact angles titrated on coal samples of five surfactants at different concentrations in Hancheng block, the test results are shown in Table.2 (multiple determinations take average):

| reagent number mass concentration | B1 | B2 | B3 | B4 | B5 |
|---------------------------------|----|----|----|----|----|
| 0.05%                           | 8.6| 25.9| 38.9| 0  | 9.1|
| 0.08%                           | 7.2| 28.2| 28.5| 0  | 8.7|
| 0.1%                            | 7.1| 25.0| permeation | 0 | permeation |
| 0.2%                            | 0  | 0  | permeation | 0 | permeation |
| 0.5%                            | 0  | 0  | permeation | 0 | permeation |
| 1.0%                            | 0  | 0  | permeation | 0 | permeation |

According to the test, the test result of contact angle of the 0.5% KCl solution on the coal rock samples is 92.5°in the Hancheng block, by contracting the test results in Table.2, it can be seen that the wetting performances of B1, B2 and B4 are stronger, while B3 and B5 show good permeation performance. As can be known from the capillary force calculation formula (formula1), smaller contact angles leads to the increase of capillary force, which is not conducive to the removal of water blocking damage, therefore, B1, B2 and B4 should not be selected; Considering that there is low mechanical strength, strong permeability, low surface tension in the coalbed methane reservoirs of Hancheng block, and the solution that is easy to inject is the best choice. B3+B5 were selected as the preliminary formula of the coal reservoir water blocking agent in combination with the determination results of surface tension.

\[ P_c = 2\delta \cos \theta \frac{r}{\cos \delta} \]  

(1)

In the formula: \( P_c \) is the capillary force, \( r \) is the pore radius, \( \delta \) is the interfacial tension, and \( \theta \) is the contact angle.

Practice indicates that non-ionic and anionic surfactants often present good synergistic effects, therefore, the mixed experiment was conducted for to obtain the preliminary formula C1: 0.1% B3+0.05% B5.

3. Optimization of Auxiliaries

When small molecular alcohols as additives, they have several effects: (1) small molecular alcohols themselves have the capacity to reduce surface tension; (2) small molecular alcohols have a certain effect on inhibiting clay expansion and defoaming; (3) small molecule alcohols often have the characteristics of low boiling point and volatility, and can form a low-boiling azeotrope with the formation liquid, which is easy to gasification and discharge, thereby reducing water block damage. On the basis of the above considerations, combined with the current construction requirements for environmental protection, after reference research, ethanol was finally selected as the auxiliary of formula. [7-9]
3.1. Surface tension experiment
The determination results of surface tension under different conditions of ethanol addition were determined, as shown in Fig.2:

![Fig.2](image)

The comparison shows that the addition of ethanol can reduce the surface tension of the system, but the effect is no longer obvious after the addition exceeds 1%. When determining the contact angle, several solutions dripped on the coal sample and quickly penetrated, meeting the permeability requirements. Ethanol shows a good synergy with the mixed surfactant solution.

![Fig.3 Before dripping ethanol](image)  ![Fig.4 After dripping ethanol](image)

After the mixed surfactant solution was stirred, bubbles will appear at the air-water interface; after 1% ethanol was dripped, most of the interface bubbles disappear, which reflects the defoaming effect of ethanol. It is easy to generate bubbles in the process of configuring on-site solution, which is unfavorable for the removal of water blocking damage; therefore, it is necessary to add ethanol to the mixed surfactant system.

3.2. Water absorption/release experiment of coal and rock
By consulting the national standard GB/T 23561.5-2009 of "Determination Methods of Physical and Mechanical Properties of Coal and Rocks"[10], active water and surfactant solutions with different amounts of ethanol were used to determine the water absorption and water release capacity of coal sample, the injection ease and flow back capacity of the mixed surfactant solution were contrasted and tested, the experimental results are as follows:
According to the experimental test results, the absorption and release capacity of the coal samples to the formula solution is significantly higher than that of the activated water, and when the ethanol content is higher than 3%, this improvement effect is no longer significant. This reflects that the formula solution has good injection and flow back capacity to a certain extent. Combining the above experimental results, the indoor experimental formula of coal seam water blocking agent PT was obtained: 0.1% B3 + 0.05% B5 + 3% ethanol.

4. Laboratory Evaluation Experiment

4.1. Basic physical property analysis

The formula was sent to Beijing ZKGX Research Institute of Chemical Technology for basic physical property analysis. The test results are shown in Table.3, which meets the requirements for well safety and environmental protection of field tests.
Table 3: Basic physical property analysis of water blocking agent PT in coal seam

| Effective content | 3.15% |
|-------------------|-------|
| Effective composition content | B5 0.05% 4440-54-4 |
| | B3 0.1% 1639-66-3 |
| | Ethanol 3% 64-17-5 |
| Color | Colorless or light yellow transparent liquid |
| Smell | Slightly pungent smell or tasteless |
| Toxicity | Non-toxic, swallow is harmful |
| PH | 6-7 |

4.2. Evaluation of water blocking agent

In order to better evaluate the removal effect of water blocking, Automatic displacement acquisition device was used to conduct laboratory water block removal experiment for formula solution at 100°C, the test steps and results are as follows:

(1) The coal sample was saturated with 0.5% KCl solution; (2) The gas was bubbled into the rock core from one end and the permeability K1 before liquid injection was determined; (3) The gas was bubbled into test solution in the reverse direction; (4) gas was bubbled in the forward direction, the permeability K2 after injection was determined.

Table 4: The first set of test results

| Distilled water | C1 | C1+1% ethanol | C1+3% ethanol | C1+5% ethanol |
|-----------------|----|---------------|---------------|---------------|
| K1, mD          | -- | 0.0096        | 0.0112        | 0.0133        | 0.0131        |
| K2, mD          | -- | 0.0263        | 0.0362        | 0.0689        | 0.0749        |
| Growth rate     | -- | 2.75          | 3.23          | 5.18          | 5.72          |

Table 4: The second set of test results

| Distilled water | C1 | C1+1% ethanol | C1+3% ethanol | C1+5% ethanol |
|-----------------|----|---------------|---------------|---------------|
| K1, mD          | -- | 0.0127        | 0.0084        | 0.0124        | 0.0107        |
| K2, mD          | -- | 0.0249        | 0.0223        | 0.0779        | 0.0575        |
| Growth rate     | -- | 1.96          | 2.66          | 6.28          | 5.37          |

In the process of experiment, the distilled water was injected slowly even when the injection pressure reached 15 MPa, and the permeability could not be measured, and confirmed that the injected solution must have good permeability. According to the experimental results, when the ethanol addition reaches 3%, the permeability recovery effect is better, and the permeability increase effect is not significant after the addition exceeds 3%, which is consistent with the results of the water absorption and release experiment of coal sample. The results of laboratory experiments show that the gas-phase permeability increases under low permeability conditions after using the water blocking agent, which can achieve the effect of water blocking removal.

5. Conclusion

(1) Five surfactants are selected to determine the surface tension and contact angle of surfactants with different concentrations, the results show that the mixture of anionic surfactant B3 and nonionic surfactant B5 have good performance to reduce surface tension reduction and permeation, and meets the demand for water blocking removal.
(2) In allusion to the problem of easy foaming in the solution preparation process, ethanol was selected as the formula auxiliary and conducted evaluation experiments, the results showed that ethanol and the mixed surfactant solution have synergistic effects and good defoaming capacity, and the effect is best when the addition is 3%, which meets the economic requirements.

(3) The formula of coal seam water blocking agent PT is determined through basic physical property evaluation and water blocking laboratory experiments, the results show that the formula solution meets the environmental protection requirements when the liquid flows into the well in the field test, and the gas-phase permeability after laboratory application is increased by more than 5 times.

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