Research and Application of Fracturing Fluid Preparation with Produced water in Erlian Oilfield

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Abstract: Aiming at the problem of shortage of clean water resources and mixing fracturing fluid in winter in Erlian oilfield, the technology of producing water to prepare fracturing fluid was studied. Horizontal comparison of water samples from four combined oil and gas treatment stations shows that oil, surfactant and bacteria are the main factors that affect the indigestion of hydroxypropyl guar gum in oilfield produced water. Through the indoor research developed a new type of multi-functional cosolvent and explored the oilfield produced water confecting fracturing fluid formulation system: 0.3-0.5% hydroxypropyl guar gum +X% multifunctional cosolvent + 0.2% flow-back agent + 0.4-0.6% crosslinking agent. This technology simplifies the mixing process and reduces the amount of additives. The liquid still has a high viscosity after being placed for more than 3 to 4 days in summer. In winter, using the produced water for mixing can reduce the influence of environmental temperature and ensure the smooth construction. After field application in well h5-19, the effect is outstanding, which provides important technical support for follow-up fracturing construction in Erlian oilfield.

1. Introduction
Fracturing technology has become a tool for low-permeability reservoir reconstruction. With the continuous progress of science and technology in recent years, the scale of fracturing is increasing, and the amount of fracturing fluid is also increasing. At present, the application of water-based fracturing fluid accounts for more than 90% of the total amount of fracturing fluid. However, with the depletion of water resources and the increasing amount of produced water, researchers began to study the use of produced water to prepare fracturing fluid.

The produced water has the characteristics of petroleum, impurity, scale forming ion and surfactant. After the efforts in recent years, some progress has been made, such as Kehinde s. Bankole in the United States, Juanjuan Wang, Hu Sun, Tongyi Liu, Chong Liu, Ziwie Chen and others in China, who also carried out research on the preparation of fracturing fluid with produced water of oil fields and achieved certain research results. However, in terms of thickeners, most of the thickeners used to prepare fracturing fluid by using oilfield produced water are associated polymers. After the
fracturing, the sand-carrying fluid is not broken completely, causing great damage to the formation. Some of them need to add more kinds of additives and fungicides when using guar gum as thickener to prepare fracturing fluid [8]. Therefore, based on the analysis of the produced water in the four combined oil and gas stations of Erlian oilfield, the author developed a multi-functional auxiliary agent according to the analysis results, and finally formed the formula of producing water to prepare fracturing fluid in Erlian oilfield and successfully realized the field application.

2. Characteristics of produced water in Erlian oilfield

According to the experimental requirements, sampling and analysis were conducted on the clear water, settlement tank outlet sewage and filtered sewage of the four stations A1, B1, H1 and A2 respectively. The appearance and pH values were shown in table 1.

Table 1. Analysis results of appearance and pH value of produced water in four treatment stations

| Samples of treatment stations | Appearance                                      | pH  |
|------------------------------|-------------------------------------------------|-----|
| Settlement tank outlet sewage | Shallow black, turbidity, odor and oil           | 7.5 |
| A1 Clear water               | Colorless, odorless and transparent              | 7   |
| Filtered sewage              | Pale yellow, cloudy and smelly                   | 7.5 |
| Settlement tank outlet sewage | Pale yellow, slightly muddy, smelly and oily   | 8   |
| B1 Clear water               | Colorless, odorless and transparent              | 7.5 |
| Filtered sewage              | Pale yellow, slightly muddy and smelly           | 8   |
| Settlement tank outlet sewage | Pale yellow, slightly muddy, slightly oily      | 7   |
| H1 Clear water               | Colorless, odorless and transparent              | 7   |
| Filtered sewage              | Light yellow, slightly muddy                     | 7   |
| Settlement tank outlet sewage | Slightly yellow transparent, slightly oily      | 7   |
| A2 Clear water               | Colorless, odorless and transparent              | 7   |
| Filtered sewage              | Slightly yellow transparent                      | 7   |

3. Study on fracturing fluid system of produced water in oilfield

3.1 The causes of non-swelling of guar gum were explored by contrast and elimination

The most important index to evaluate fracturing fluid is its ability to withstand temperature and shear [9]. According to SY/T 5107-2016 "Performance evaluation method of water-based fracturing fluid”, water samples from four stations were taken to prepare fracturing fluid. The results are shown in table 2.

Table 2. The swelling situation of 0.35% hydroxypropyl guar gum at different station water samples

| Samples of treatment stations | Viscosity after 10 min (mPa.s) | Viscosity after 4 days (mPa.s) | Viscosity retention (%) |
|------------------------------|---------------------------------|--------------------------------|-------------------------|
| Clear water                  | 37.5                            | 36.5                           | 97.3                    |
| A1 Settlement tank outlet sewage | 1                               | /                              | /                       |
| Filtered sewage              | 1                               | /                              | /                       |
| Clear water                  | 42                              | 41.3                           | 98.3                    |
| B1 Settlement tank outlet sewage | 1                               | /                              | /                       |
| Filtered sewage              | 1                               | /                              | /                       |
| Clear water                  | 39                              | 38.2                           | 97.9                    |
| H1 Settlement tank outlet sewage | 1                               | /                              | /                       |
| Filtered sewage              | 1                               | /                              | /                       |
| Clear water                  | 31.5                            | 30.6                           | 97.1                    |
| A2 Settlement tank outlet sewage | 21.6                            | 5.2                            | 24.1                    |
| Filtered sewage              | 18.4                            | 3                              | 16.3                    |

It was found that hydroxypropyl guar gum could be dissolved in clear water samples of various stations with good viscosity retention, but could not be dissolved in produced water of A1, B1 and H1.
Although it can be dissolved in the produced water at A2, the viscosity retention rate is low and cannot meet the normal construction requirements. Therefore, water samples from the four stations were analyzed according to SY/T 5329 – 2012 "Recommended water quality indexes and analysis methods for injected water quality in clastic reservoir" and SY/T 5523-2016 "Oilfield water analysis methods". The results are shown in table 3 and figure 1.

Table 3. The results of the water sample analysis at different stations

| Samples of treatment stations | CO\(^3\) mg/L | HCO\(^3\) mg/L | Cl mg/L | SO\(^4\) mg/L | Na\(^+\)+K \(^+\) mg/L | Ca\(^2+\) mg/L | Mg\(^2+\) mg/L | Salinity mg/L | Oil content mg/L | Iron ions mg/L | SRB PCS/mL | TGB PCS/mL | IB PCS/mL |
|------------------------------|---------------|-----------------|---------|---------------|-----------------------|--------------|--------------|---------------|----------------|---------------|-----------|-----------|-----------|
| A1 Settlement tank outlet sewage | -             | 1268.2          | 534.6   | 23.1          | 813.7                 | 10.7        | 5.24        | 2655.5        | 1.3            | 0.96          | 2.5×10^7  | 2.5×10^7  | 0.6        |
| A1 Filtered sewage           | -             | 1314            | 528.3   | 49.9          | 822.3                 | 16.3        | 11.1        | 2741.9        | 9.2            | 0.7           | 2.5×10^7  | 2.5×10^7  | 0.6        |
| A1 Clear water               | -             | 580.6           | 402.5   | 154.7         | 424.6                 | 57.9        | 33.29       | 1653.6        | -              | 0.2           | -         | -         | -         |
| A1 Settlement tank outlet sewage | -           | 4461.8          | 339.4   | 1914.5        | 2795.6                | 4           | 2.43        | 9497.7        | 43.6           | 0.7           | 2.5×10^10 | 2.5×10^10 | 2.5×10^9   |
| B1 Filtered sewage           | 144           | 3703.9          | 417.6   | 2021.1        | 2684.1                | 12          | 24.55       | 9007.2        | 0.5            | 0.7           | 2.5×10^10 | 2.5×10^10 | 2.5×10^9   |
| B1 Clear water               | -             | 397.2           | 37.6    | 1934.6        | 988.8                 | 44.5        | 31.8        | 3434.5        | -              | 0.1           | -         | -         | -         |
| B1 Settlement tank outlet sewage | -           | 1375.1          | 78.6    | 13.4          | 558.2                 | 10.2        | 3.1         | 2038.6        | 8.5            | 1.38          | 6.0×10^7  | 2.5×10^7  | 2.5×10^9   |
| H1 Filtered sewage           | -             | 1298.7          | 333.3   | 99.9          | 714.5                 | 10.2        | 14.5        | 2471.1        | 6.7            | 0.45          | 6.0×10^7  | 2.5×10^7  | 2.5×10^9   |
| H1 Clear water               | -             | 550.1           | 295.6   | 146.2         | 343.1                 | 46.8        | 38.2        | 1420.0        | -              | 0.2           | -         | -         | -         |
| H1 Settlement tank outlet sewage | -           | 3055.9          | 377.3   | 3.7           | 1381.5                | 7.1         | 4.62        | 4830.1        | 15.3           | 1.12          | 2.5×10^7  | 2.5×10^7  | 6.0×10^7   |
| A2 Filtered sewage           | 30.1          | 3086.4          | 377.3   | 376.4         | 1422.5                | 6.1         | 96.2        | 5395.0        | 6.6            | 0.7           | 2.5×10^7  | 2.5×10^7  | 6          |
| A2 Clear water               | -             | 733.4           | 94.3    | 290           | 445                   | 13.7        | 8.3         | 1584.7        | -              | 0.2           | -         | -         | -         |

As can be seen from table 3, the content of HCO\(^3\) in sewage is more than twice as high as that in clean water, and CO\(^3\)- still exists in the filtered sewage of B1 and A2 combined station. The total iron content in the produced water is 3 times higher than that in the clean water.

![Figure 1. Surface tension of water samples at different stations](image-url)

According to the test results of SRB, TGB and IB, a large number of bacteria were found in the extracted water. At the same time, according to the test results in figure 1, the surface tension of produced water in each station is lower than that of clean water, indicating that the produced water in each station contains a certain amount of surfactant.

3.1.1 Carbonate and iron exclusion experiment
Taking A1 clear water as an example, different amounts of sodium bicarbonate and ammonium ferric
sulfate reagent were added in the clear water to simulate carbonate and iron ions, to study the swelling situation of melon gum in the water sample, and to test the viscosity of the base solution when stirred for 10min.

![Figure 2. Influence of bicarbonate concentration](image1)

![Figure 3. Influence of iron concentration](image2)

Figure 2 and figure 3 show that, within a certain range, the increase of bicarbonate ion and iron ion concentration does not affect the swelling of guar gum, but only slightly affects the viscosity after swelling.

3.1.2 Inorganic salt exclusion experiment

Distilled water was used to prepare simulated water sample A (2.0% potassium chloride, 5.5% sodium chloride, 0.45% magnesium chloride, 0.55% calcium chloride, 0.4% sodium bicarbonate, 0.1% ammonium ferric sulfate). Water samples A and distilled water were mixed in different proportions to form the mixture solution, and the viscosity of the base solution was tested after stirring for 10min.

![Figure 4. Viscosity of base fluid after mixing water sample A with distilled water in different proportions](image3)

![Figure 5. Test results of temperature and shear resistance of gels after crosslinking in different proportions](image4)

The above experimental results show that: within a certain range, the concentration of inorganic salts only affects the viscosity and the temperature and shear resistance of the gel; the sewage contains oil, some surfactants and bacteria, which affect the swelling ability and viscosity retention ability of hydroxypropyl guar gum in oilfield produced water.

3.2 Exploration on formulation of produced water fracturing fluid

In view of the situation that hydroxypropyl guar gum is insoluble in the produced water at various stations, the author has developed a multifunctional cosolvent through a large number of laboratory experiments.
experiments, which can not only promote the thickener (guar gum) to dissolve in the liquid faster and more fully, but also has anti-inflation, sterilization and other functions.

400mL extracted water +X% cosolvent +0.3-0.5% guar was selected from each station to prepare the base fluid. Firstly, the viscosity was tested at room temperature of 30℃, as shown in figure 6. Then, the temperature and shear resistance of the gel was tested (80℃, 170s⁻¹, 90min shear), and compared with the clear water in different stations, as shown in figure 7.

It can be seen from figure 6 that the cosolvent has a good sterilization function, and the liquid still maintains a high viscosity after being placed at 30℃ for 4 days. Therefore, the liquid prepared on site in summer can be placed for 3-4 days without adding fungicide, which saves the cost of fungicide. As can be seen from figure 7, the temperature and shear resistance of gels formed by the addition of crosslinking agent in the base fluid also met the requirements of the index. Based on the experimental results, the fracturing fluid formulation of produced water in Erlian oilfield was finally determined.

![Figure 6. Comparison between the initial viscosity and the viscosity after 4 days](image)

![Figure 7. Comparison of temperature and shear resistance of gels](image)

### 4. Performance evaluation

#### 4.1 Evaluation of temperature and shear resistance

The fluid prepared with produced water was evaluated by using HAAKE MARS rotary rheometer at 80℃ and shear rate of 170s⁻¹ according to the formula of 0.3-0.5% hydroxypropyl guar +X% cosolvent +0.2% drainage aid + produced water + 0.4-0.6% crosslinking agent. After the test, the viscosity retention rate is above 50mPa•s, with good temperature and shear resistance (As shown in figure 8).
4.2 Sand-carrying performance evaluation
Mix the prepared fracturing fluid with the proppant at a volume ratio of 100:40, add the crosslinking agent and mix it evenly to form gel, and observe the settlement of the proppant, as shown in figure 9. After placing for 60min, it was observed that the proppant did not appear significant settlement in either of the two fracturing fluids, indicating that the fracturing fluid prepared with produced water had good sand-carrying performance and fully met the construction requirements.

4.3 Performance evaluation of rubber breaking
After fracturing, the return flow of gel is also a crucial link. The performance of fracturing fluid prepared with produced water is evaluated in the laboratory. The breaking agent is ammonium persulfate, the breaking temperature is 80℃, and the breaking time is 1h. Through the experiment, it was found that the fracturing fluid had good breaking performance and low surface tension (see table 4).

| Amount of breaking agent | Viscosity(mPa·s) | Properties | pH     | Surface tension(mN/m) |
|--------------------------|-----------------|------------|--------|----------------------|
| 0.0005%                  | Partial hydration| -          | -      | -                    |
| 0.0010%                  | Partial hydration| -          | -      | -                    |
| 0.0050%                  | Partial hydration| -          | -      | -                    |
| 0.0100%                  | Partly broken    | -          | -      | -                    |
| 0.0500%                  | 7.5              | 8.5        | 25.90  |                      |
| 0.1000%                  | 4.3              | 8.0        | 24.41  |                      |

5. Application
Well h5-19 is a high liquid and low oil well in Hanan area of Erlian oilfield. After communication with geological and engineering personnel, it is considered that the well still has certain development potential, so it is decided to select the well as the test well. In October 2019, 300 cubic meters of fracturing fluid were prepared by using the produced water from the H1 station, and the fracturing operation was successfully completed. After fracturing, it can realize self-spraying, with a daily output of liquid 2.5t and oil 1.7t.
6. Conclusion
(1) Through comparative analysis of produced water in four treatment stations of Erlian oilfield, it was found that the produced water contained impurities such as petroleum, surfactant and bacteria, which affected the swelling capacity of hydroxypropyl melon powder in produced water and the viscosity retention rate of the base liquid.

(2) Through the research and development of auxiliary solvent, the problem of swelling of hydroxypropyl melon gum in produced water was effectively solved. Meanwhile, the prepared fracturing fluid had excellent performance, and all the indexes met the requirements of fracturing reconstruction in Erlian oilfield. The field application effect was good, and effectively filled the technical gap of preparing fracturing fluid from produced water in Erlian oilfield.

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