Study on the Influence of Jelly in Polymer Flooding Injection System on Oil Displacement Efficiency

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Abstract. In this paper, the composition and production conditions of viscous gelatinous substances in the inner walls of filters and pipelines in polymer injection system are analyzed in detail, and the influence of gelatinous substances on the development effect of polymer flooding is studied. A new understanding of the influence of gelatinous substances on the development effect of polymer flooding is obtained. In view of the harmfulness of gelatinous substances, treatment suggestions are put forward and positive countermeasures are taken for industrial field. It has important reference value.

1. Introduction
In the process of polymer preparation and injection, a large number of colloidal substances are attached to the inner walls of filters and pipelines, which has a negative impact on the normal operation of polymer solution preparation and injection system. Once the gelatinous material falls off from the pipe wall and enters the wellbore, the reservoir permeability near the wellbore will be reduced and the injection pressure will be increased, which will result in injection difficulties and affect the oil-increasing effect of polymer flooding.

2. Components and sources of colloids
In the injection system, a large number of black and yellow gelatinous substances with irritating odor were found in the mixing station and the filter of the injection station, along with the formation of black substances and pungent rotten odor with the prolongation of the storage time. In order to clarify the main components of gelatinous substance, three samples were analyzed: polyacrylamide (19 million molecular weight dry powder from Daqing Refinery and Chemical Company); sediment on the tank wall of mother liquor filter of preparation station (hereinafter referred to as jelly 1); and viscous liquid containing polymer (hereinafter referred to as jelly 2) collected from filter before injection pump.

2.1. The main components of gelatin are polyacrylamide and its degradation products, containing a small amount of mucopolysaccharide and organic acid.
According to the analysis of mass change data before and after burning, jelly 2 have higher inorganic content and similar properties, mainly polyacrylamide, while jelly 1 has lower inorganic content, which contains other organic substances such as microbial metabolites besides polyacrylamide.
Table 1. Measurement Data of Mass Change of Samples Before and after Burning

| Sample     | Weight/g | Weight after burning/g | Mass loss/g | Organic compound(%) | Inorganic compound(%) |
|------------|----------|------------------------|-------------|---------------------|----------------------|
| polyacrylamide | 0.4441   | 0.0884                 | 0.3557      | 80.09               | 19.91               |
| Jelly 1    | 0.1123   | 0.0035                 | 0.1088      | 96.88               | 3.12                |
| Jelly 2    | 0.1376   | 0.0024                 | 0.1136      | 82.56               | 17.44               |

The content of mucopolysaccharide in inorganic polyacrylamide is very small. The content of mucopolysaccharide in jelly 1 and jelly 2 is high, reaching 287 mg/L and 336 mg/L, respectively. Therefore, the main components of the gelatin are polyacrylamide and its degradation products, containing a small amount of mucopolysaccharide and organic acid.

2.2. The production of adhesives and colloids has a certain relationship with microbial activities.

The main components of adhesive and colloids are polyacrylamide, which is mainly caused by the "fish eye" attached to the filter bag or the filter net caused by the insoluble dry polymer powder; secondly, the gelatinous substance is related to the microbial activity, which contains a large number of biological metabolic products and information, such as mucopolysaccharide, acetic acid and butyric acid, which are closely related to the microbial activity. Jelly 2 has the high content of S and Fe that may be due to the reduction of $\text{SO}_4^{2-}$ to $\text{S}_2^-$ by sulfate reducing bacteria, and form black FeS.

Because microorganisms produce biological enzymes, polyacrylamide is hydrolyzed and the amide groups are removed. Therefore, the contents of N and H in both jelly 2 and jelly 1 are reduced.

3. Damage of colloids

3.1. Damage of gelatinous substances Degradable gelatinous polymers and blockage of reservoirs

3.1.1. The type and content of colloids have an effect on the viscosity of polymer solution.

The viscosities of different types of solutions with different contents are shown in Table 2. From Table 2, it can be seen that the viscosities increase with the addition of jelly 1 in polymer solutions, and increase with the addition of jelly 2. After the addition of jelly 2, the viscosities decrease, and decrease with the increase of the addition of jelly 1.

Table 2. Viscosity Contrast Table for Different Contents of Different Solutions

| Sample    | Viscosity/mPa.s |
|-----------|-----------------|
|           | 0               | 2%  | 4%  | 8%  |
| Jelly 1   | 32.3            | 35.3| 37.8| 44.6|
| Jelly 2   | 32.3            | 30.8| 28.9| 26.6|

3.1.2. The stability of polymer solutions containing colloids becomes worse.

The comparison table of viscosity loss of different types of solutions under different time conditions is shown in Table 3. It can be seen from Table 3 that under different types of colloids, the viscosity of polymer solutions decreases with the prolongation of storage time, and the decrease range of polymer solutions containing jelly 2 is larger.

Table 3. Viscosity Loss Contrast Table for Different Types of Solutions at Different Time Conditions

| Sample                     | Viscosity/mPa.s |
|----------------------------|-----------------|
|                            | 0 d             | 1 d  | 10 d | 30 d  | 60 d  |
| Polymer Solution Containing | Jelly 2         | 28.9 | 25.3 | 19.8  | 15.1  | 3.8   |
| Polymer Solution Containing | Jelly 1         | 37.8 | 30.7 | 21.7  | 18.0  | 10.7  |
| Polymer Solution            | 32.3            | 32.0 | 30.6 | 27.3  | 24.0  |
3.1.3. *The gelatin has little effect on the temperature resistance of polymer solution.* The viscosity loss of different types of solutions at different temperatures is shown in Table 4. It can be seen from Table 4 that the viscosities of colloidal and polymer solutions decrease with the increase of test temperature, but the difference is not significant.

| Sample                               | Viscosity/mPa.s |
|--------------------------------------|-----------------|
|                                      | 25°C | 35°C | 45°C | 55°C |
| Polymer Solution Containing Jelly 2  | 22.3  | 17.1  | 13.3  | 11.6 |
| Polymer Solution Containing Jelly 1  | 41.7  | 36.4  | 32.7  | 29.9 |
| Polymer Solution                      | 35.5  | 31.2  | 27.3  | 24.5 |

3.1.4. *The rheological properties and viscoelasticity of polymer solutions containing colloidal substances become worse.* The relationship between apparent viscosity and shear rate, storage modulus and oscillation frequency is shown in Figure 1 and Figure 2, respectively. It can be seen from Figure 1 and Figure 2 that the shearthinning rheological characteristics of polymer solution are similar to those of ordinary polymer solution when different types of colloids are added into polymer solution. Under the same conditions the apparent viscosity of polymer solution is the highest, followed by polymer solution containing colloidal substance 1 and polymer solution containing colloidal substance 2. The viscoelasticity of polymer solution containing colloidal substance decreases with the increase of oscillation frequency.

3.1.5. *The colloids have an effect on the molecular aggregation in polymer solution.* In polymer solution containing jelly 1, the aggregated state of polymer molecule still presents spatial network structure, but the structure becomes sparse and the network skeleton becomes finer. In polymer solution containing jelly 2, the aggregated network structure of polymer molecule appears defects and the molecular chain breaks, resulting in the decrease of the ability of structure to encapsulate water molecules and the decrease of viscosity.

After 30 days of storage, the aggregation state of polymer molecules changed greatly. After these days, the aggregated network structure of polymer molecules became sparse, and the network presented spherical particles, which formed Beaded structure with each other. In polymer solution containing jelly 1, the backbone of polymer molecular network retracts, some network structures break, and the original
aggregation state is destroyed. In polymer jelly 2, the aggregates of polymer molecules present spherical particles without entanglement with each other, resulting in serious structural damage.

3.2. Gelatin can plug reservoirs
The type, content and core permeability of colloids have influence on the percolation characteristics of polymer solution. Table 5 shows that with the decrease of core permeability, the resistance coefficient and residual resistance coefficient of polymer solution increase; with the increase of gelatin content, the resistance coefficient and residual resistance coefficient of polymer solution increase; the influence of jelly 1 on the percolation characteristics of polymer solution is greater than that of jelly 2.

Table 5. Comparisons of Resistance Coefficient and Residual Resistance Coefficient of Colloids with Different Contents

| Colloidal Content /% | Viscosity /mPa.s | Permeability /mD | Resistance Coefficient | Residual Resistance Coefficient | Viscosity /mPa.s | Permeability /mD | Resistance Coefficient | Residual Resistance Coefficient |
|---------------------|------------------|------------------|------------------------|-------------------------------|------------------|------------------|------------------------|-------------------------------|
| 0                   | 20.1             | 109              | 30.5                   | 25.1                          | 20.1             | 109              | 30.5                   | 25.1                          |
|                     |                  | 211              | 28.0                   | 15.6                          |                  | 211              | 28.0                   | 15.6                          |
|                     |                  | 513              | 23.5                   | 13.5                          |                  | 513              | 23.5                   | 13.5                          |
|                     |                  | 1034             | 12.0                   | 9.3                           |                  | 1034             | 12.0                   | 9.3                           |
| 2                   | 16.5             | 102              | 201.4                  | 183.9                         |                  | 103              | 151.7                  | 122.9                         |
|                     |                  | 214              | 120                    | 92.6                          |                  | 214              | 104                    | 80                            |
|                     |                  | 510              | 62.5                   | 44.1                          |                  | 510              | 78.2                   | 58.2                          |
|                     |                  | 1028             | 53.3                   | 37.3                          |                  | 1036             | 42.7                   | 28                            |
| 4                   | 14.5             | 109              | 234.8                  | 201.1                         |                  | 109              | 224.1                  | 197.7                         |
|                     |                  | 216              | 170.2                  | 128.8                         |                  | 211              | 148                    | 113.4                         |
|                     |                  | 517              | 119.6                  | 100                           |                  | 501              | 113.1                  | 82.6                          |
|                     |                  | 1044             | 109.3                  | 90.7                          |                  | 1037             | 56.7                   | 36                            |
| 8                   | 12.6             | 108              | 244.8                  | 229.8                         |                  | 114              | 298.9                  | 258.6                         |
|                     |                  | 207              | 200                    | 170                           |                  | 214              | 240                    | 180                           |
|                     |                  | 518              | 169.6                  | 144.8                         |                  | 518              | 200                    | 152.2                         |
|                     |                  | 1085             | 141.3                  | 130.7                         |                  | 1045             | 180                    | 136.7                         |

3.3. The gelatinous solution has a great influence on enhancing oil recovery
The presence of colloids results in poor transport capacity of polymer solutions, which in turn affects the effect of expanding sweep volume. The comparison tables of different schemes under constant velocity and constant pressure conditions are as follows: Table 6. It can be seen from Table 6 that under constant velocity or constant pressure injection conditions, with the increase of permeability gradient the influence of colloids on the oilincreasing effect of polymers decreases, and the influence of colloids on the diversion rate of low permeability layers is greater. Comparing the two injection processes, the influence on the oilincreasing effect of polymer flooding mainly depends on the core permeability gradient: the oilincreasing effect is better when the permeability gradient is 2; the oilincreasing effect is better when the permeability gradient is 5 and 10; when the core permeability gradient is 5 and 10, the injection pressure of constant-speed injection is lower than that of constant pressure injection, which results in the decrease of the suction hydraulic difference of low per meability layer. The ripple effect becomes worse.
### Table 6. A comparative table of recovery rates for different schemes under constant velocity and pressure conditions

| Project | Permeability ratio | Content | Permeability of each layer /mD | Oil Saturation /% | Recovery efficiency/% | Water Drive | Final Result | Increase Range |
|---------|--------------------|---------|--------------------------------|-------------------|------------------------|-------------|--------------|----------------|
|         |                    |         |                                |                   |                        |             |              |                |
| 2 times |                    | Water Drive to 98%+ 0.3PV Polymer Solution 200 | 67.66 | 42.9 | 64.2 | 21.3 |
|         |                    | 100     | 65.27 | 38.5 | 70.3 | 31.8 |
|         |                    | Parallel Model | 66.22 | 39.4 | 64.9 | 25.5 |
|         |                    | Water Drive to 98%+ 0.3PV Polymer Solution with Jelly 200 | 67.48 | 42.5 | 48.1 | 5.6 |
|         |                    | 100     | 65.19 | 38.5 | 55.8 | 17.3 |
|         |                    | Parallel Model | 66.39 | 39.2 | 50.2 | 11.0 |
| 5 times | Water Drive to 98%+ 0.3PV Polymer Solution 500 | 69.39 | 45.3 | 49.6 | 4.3 |
|         |                    | 100     | 65.37 | 18.9 | 30.5 | 11.6 |
|         |                    | Parallel Model | 67.64 | 33.6 | 44.1 | 10.5 |
|         |                    | Water Drive to 98%+ 0.3PV Polymer Solution with Jelly 500 | 69.01 | 45.3 | 49.6 | 4.3 |
|         |                    | 100     | 65.19 | 19.3 | 35.9 | 16.6 |
|         |                    | Parallel Model | 66.59 | 33.2 | 50.1 | 16.9 |
| 10 times| Water Drive to 98%+ 0.3PV Polymer Solution 1000 | 71.66 | 48.6 | 53.9 | 5.3 |
|         |                    | 100     | 65.73 | 8.3  | 23.5 | 15.2 |
|         |                    | Parallel Model | 69.11 | 32.5 | 41.4 | 8.9  |
|         |                    | Water Drive to 98%+ 0.3PV Polymer Solution with Jelly 1000 | 71.41 | 49.3 | 53.4 | 4.1  |
|         |                    | 100     | 65.45 | 8.3  | 16.0 | 7.7  |
|         |                    | Parallel Model | 68.84 | 32.1 | 38.3 | 6.2  |
| 2 times | Water Drive to 98%+ 0.3PV Polymer Solution 200 | 67.5  | 43.0 | 57.3 | 14.3 |
|         |                    | 100     | 65.3  | 37.0 | 55.2 | 18.2 |
|         |                    | Parallel Model | 66.5  | 40.3 | 56.4 | 16.1 |
|         |                    | Water Drive to 98%+ 0.3PV Polymer Solution with Jelly 200 | 67.8  | 41.3 | 49.0 | 7.7  |
|         |                    | 100     | 65.4  | 37.7 | 48.2 | 10.5 |
|         |                    | Parallel Model | 66.7  | 39.7 | 48.7 | 9.0  |
| 5 times | Water Drive to 98%+ 0.3PV Polymer Solution 500 | 69.4  | 45.5 | 54.6 | 9.1  |
|         |                    | 100     | 65.4  | 19.4 | 39.9 | 20.5 |
|         |                    | Parallel Model | 67.6  | 34.1 | 48.3 | 14.2 |
|         |                    | Water Drive to 98%+ 0.3PV Polymer Solution with Jelly 500 | 69.8  | 44.2 | 51.4 | 7.2  |
|         |                    | 100     | 65.7  | 18.7 | 34.4 | 15.7 |
|         |                    | Parallel Model | 68.0  | 33.3 | 44.1 | 10.8 |
| 10 times| Water Drive to 98%+ 0.3PV Polymer Solution 1000 | 71.7  | 47.7 | 55.2 | 7.5  |
|         |                    | 100     | 65.2  | 7.5  | 26.6 | 19.1 |
|         |                    | Parallel Model | 69.0  | 32.0 | 44.1 | 12.1 |
|         |                    | Water Drive to 98%+ 0.3PV Polymer Solution with Jelly 1000 | 72.1  | 48.3 | 54.7 | 6.4  |
|         |                    | 100     | 65.7  | 7.8  | 22.5 | 14.7 |
|         |                    | Parallel Model | 69.4  | 32.4 | 42.0 | 9.6  |

4. Measures to control reservoir damage caused by colloids
From Table 7, it can be seen that under the same experimental conditions, the viscosity of the gelatinized material not only did not decrease, but also increased considerably after the reduction of hydrogen peroxide, and there was a similar situation after the action of potassium persulfate. Further analysis shows that the viscosity of polymer solution added with colloidal substance after degradation by sodium
hypochlorite is lower than that of polymer solution without colloidal substance. This is because there is some residual after reaction between sodium hypochlorite and colloidal substance, and the residual sodium hypochlorite degrades the polymer solution, thus reducing the viscosity of polymer solution. Therefore, sodium hypochlorite is recommended for plugging removal in the concentration range of 3%-5%. From Table 8 and Table 9, it can be seen that the plugging removal time is 30 to 50 minutes, and the best time is when the injection pressure approaches the breakdown pressure.

Considering that a small amount of gelatinous material entering the high permeability layer is beneficial to improving profile and polymer flooding effect, the dosage of plugging remover should be appropriate. Excessive plugging remover not only increases the cost of agent, but also degrades the subsequent polymer solution and reduces the effect of expanding the sweep volume of polymer solution.

| Type of plugging remover | Original sample | Sodium Hypochlorite | Hydrogen peroxide | Potassium persulfate |
|--------------------------|-----------------|---------------------|-------------------|---------------------|
| Viscosity (mPa.s)        | 11.3            | 7.7                 | 33.4              | 25.4                |

| Plugging removal agent concentration /% | 2 | 3 | 4 | 5 |
|----------------------------------------|---|---|---|---|
| Viscosity (mPa.s)                      | 18.1 | 17.6 | 11.7 | 7.7 |

| Contact time/min | 10 | 30 | 50 |
|------------------|----|----|----|
| Viscosity /mPa.s | 11.8 | 11.7 | 16.0 |

5. Conclusion
The main components of gelatin are polyacrylamide and its degradation products, which contain a small amount of mucopolysaccharide and organic acid. The production of adhesives and gelatin has a certain relationship with microbial activities. Colloidal substances can cause the deterioration of solution viscosity and stability, and the destruction of polymer molecular space structure, which can lead to the poor seepage and migration ability of polymer containing solutions, and have a greater impact on enhancing oil recovery. Sodium hypochlorite can achieve better plugging removal effect but the the timing and amount of plugging removal should be appropriate.

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