Comparative Analysis of Economic Effects of Soft Microgel Flooding and Polymer Flooding

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Abstract. Soft microgel is discontinuous phase. Profile control and flooding technique of soft microgel, deferent from polymer flooding, is a technical method of secondary development of old oil fields. In this paper, we further enrich the flooding mechanism of soft microgel and propose the mechanism of targeting of oil displacement on the basis of synchronous flooding. Profile control and flooding technique of soft microgel has been applied in many oil fields at home and abroad and achieved significant effect of reducing water production and increasing oil. For evaluating the technical and economic effects, firstly, we summarize and analyse the field test results of SMG flooding technology in five oilfield blocks including Huabei oilfield, Changqing oilfield and son on. What's more, the field data of polymer flooding is investigated by consulting scientific papers. At last we compare and analyse the economic effects of soft microgel and polymer flooding by using EOR value and barrel oil cost as evaluation indexes. According to the incomplete statistical data, the economic effect of soft microgel deep flooding technology is better than that of polymer flooding technology.

1. Introduction
At present, most of the oil fields have entered or approached the middle and late stage of the development of extra-high water cut and a large amount of remaining oil is dispersed in the reservoir, which is difficult to develop individually and efficiently[1]. Xingcai Wu et al, Research Inst. Of Petroleum E&D (RIPED), CNPC, developed the Soft Microgel (SMG) flooding technology. The SMG particles in the formation behave with the actions of temporary blocking, breakthrough, and moving to another pore and repeating the actions. And the SMG particles prefer to access the relatively high permeability zones or large pores. The SMG particles behave will increase the resistance of large pore/throat, and at the same time, make the injected water diverted into small pore/throat and displace the remaining oil there, to achieve effective sweep control and improve utilization efficiency of injected water. The advantages of this technology are as follows: (1) The SMG particles, having the ability of flexible deformation, have low damage to the reservoir and will not block the seepage channel; (2) The SMG particles can be divided into nanometer, micron and submillimeter, which can be adapted to different reservoir conditions; (3) The SMG particles have higher resistance to temperature and salt(130°C, 20×10⁴mg/L); (4) The SMG particles do not expand in oil and expand in water, which can block the water flow channel which blocking the oil channel. Field tests illustrated that the Soft Microgel (SMG) flooding can drive out the remaining oil, which is highly dispersed in the reservoir, thus achieving the effect of increasing the sweep volume and enhancing the recovery[2-4].
2. Oil Displacement Theory of SMG

Reservoir water drive development is a process of continuous space and time. At different space and time point, the permeability of reservoir is different. Continuously synchronously adjusting the dominant flow direction of different classes and grades caused by the permeability differences of classes and grades in space and time can greatly improve the water drive sweep efficiency of heterogeneous oil fields, thus achieving the purpose of improving recovery. In the process of micro-flow of dispersion liquid of SMG, the SMG particles and water can achieve “division of labor and cooperation”—At different times and positions, a large number of SMG particles continuously block the water flow in the relatively high permeability or large pores and throats, while water enters the relatively low permeability or small pores/throats and displace the remaining oil there.

\[
M_{\text{HPAM}} = \frac{\mu_w}{k_w} \times \frac{k_w^*}{\mu_w} \tag{1}
\]

\[
M_{\text{SMG}} = \frac{\mu_w}{k_w} \times \frac{k_w^*}{\mu_w} \tag{2}
\]

Based on the water-displacement mobility ratio theory and Equation 1, the traditional polymer flooding get mobility ratio adjustment by increasing injection water viscosity(\(\mu_w\))[5]. But, we can see that the traditional polymer flooding, continuous phase highly viscous fluid, is to rely on viscosity to increase the flowing resistance of all the swept area, and it cannot differentiate between high and low permeability or big and small pores. In other words, the objective is to decrease the \(k_w\) and \(k_o\) in the equation. The theory of targeted oil displacement in the dispersion system is to adjust the mobility ratio through the “division of labor and cooperation” between the soft microgel (SMG) and water. The SMG particles have priority to access relatively high permeability zones or big pores and throats, to temporarily block or inhibit the flowing there (decreasing \(k_w\)), and at the same time, the water can be diverted into the relatively low permeability zones or small pores and throat, to push the remaining oil out (relatively increasing \(k_o\)), as Equation 2[5]. In this displacement process, the SMG particles can be squeezed and deform due to the follow-up pressure increase, they can breakthrough and move to the next pore/throat and temporarily block it. This dynamic process is repeated by countless SMG particles, which greatly improves the utilization efficiency of injected water, and achieves the purpose of improving mobility ratio and expanding sweep volume efficiently.

3. Economic Benefits of Soft Microgel Flooding

Five CNPC blocks (Changqing, North China, Dagang, Liaohe and Qinghai oil fields) were selected to summarize the economic and technological effects of on-site implementation[4]. As table 1, parameters include barrel oil cost of EOR, EOR, PV injected and EOR per unit injection.

| Test oilfield | Barrel oil cost of EOR (USD/bbl) | EOR(%) | PV Injected | EOR per unit injection/(g/L PV) |
|--------------|----------------------------------|--------|-------------|---------------------------------|
| Changqing    | 17.1                             | 3.42   | 0.05        | 34.2                            |
| North China  | 15.27                            | 5.8    | 0.086       | 22.48                           |
| Dagang       | 21.6                             | 3.24   | 0.08        | 20.3                            |
| Liaohe       | 21.4                             | 5      | 0.24        | 10.4                            |
| Qinghai      | 22.57                            | 3.14   | 0.08        | 19.6                            |
4. Economic Benefits of Polymer Flooding

Taking the different development stages of XSQ polymer flooding as an example in Daqing, the change trend chart of total cost in different development stages of XSQ polymer flooding does not analyze the trend of total cost in this block from the perspective of total amount[6]. However, due to the difference time span, oil production and polymer consumption in different development stages, it is necessary to conduct horizontal comparative analysis with the help of ton oil cost index.

According to the change curve of total oil cost, the change of oil cost can be divided into two stages.

1) the reduction stage of ton of oil cost: the beginning of polymer injection—the fall stage of water-cut ratio—the low water-cut stage

Initial polymer injection, we need to inject a lot of polymer, but the increase in oil is low. In this stage, the cost of a ton of oil is 2,438 yuan. After entering the period of water-cut ratio, although the increase of polymer dosage led to the increase of total cost, the increase of oil is significant, reducing the cost of a ton of oil to 2,151yuan. After the fall stage of water-cut ratio enters the low water-cut stage, the amount of oil increased reach the maximum. The increased cost of injecting the polymer is far less than the benefit of increasing the amount of oil, which leads the cost of a ton of oil reduce to 1581yuan.

2) the increasing stage of ton of oil cost: the low water-cut stage—the increasing stage of water-cut ratio—the period of subsequent water flooding

After entering the low water-cut stage, water-cut starts increasing and the increasing oil effect of polymer decreases, which leads that the ton oil cost rose from 1,581 yuan in the low water-cut stage to 1,791 yuan in the increasing stage of water-cut ratio. In the period of subsequent water flooding, as water-cut increases, oil production decreases further. And the ton of oil cost rose again, increasing to 1,543 yuan.

After the unit, the ton oil cost, is converted to the barrel oil cost, an average barrel oil cost of the traditional polymer flooding is $38.4, as table 2.

Table 2. The cost of Daqing XSQ polymer flooding project in different periods

| Application stage | The beginning of polymer injection | The fall stage of water-cut ratio | The low water-cut stage | The increasing stage of water-cut ratio | The period of subsequent water flooding |
|-------------------|-----------------------------------|----------------------------------|------------------------|----------------------------------------|----------------------------------------|
| Ton oil cost(yuan)| 2438                              | 2151                             | 1581                   | 1791                                   | 1543                                   |
| Barrel oil cost(USD/barrel) | 49.3                          | 43.5                             | 31.9                   | 36.2                                   | 31.2                                   |

By a lot of literature studying[6-9], the PV injected, pore volume, injection concentration and EOR of two different reservoirs in Daqing oilfield were calculated, calculating the corresponding EOR per unit injection, as table 3.
Table 3. The parameters of different reservoirs in Daqing

| parameter                        | The second class reservoir | The third class reservoir |
|----------------------------------|-----------------------------|---------------------------|
| Central New 201 station          | Xing Shu Gang               | Third Class Oil Layer     |
|                                  |                             | Eastern Nansi Area        |
| PV injected (mg/L PV)            | 315.43                      | 1700                      | 842.2                     |
| Pore volume (PV)                 | 0.315                       | 1.14                      | 0.7664                    |
| Injection concentration (mg/L)   | 1001                        | 1493.5                    | 1098.9                    |
| EOR (%)                          | 5.48                        | 14                        | 5.34                      |
| EOR per unit injection %         | 17.4                        | 8.2                       | 6.34                      |

According to the statistics, the second class reservoirs include the Central New 201 station and Xing Shu Gang, and the third class reservoirs include Third Class Oil Layer Eastern Nansi Area.

5. Comparison of Economic Benefit Between Soft Microgel Flooding and Polymer Flooding

Figure 1 is the column chart of EOR per unit injection for the second and third class reservoirs of polymer flooding in Daqing oilfield and Soft Microgel Flooding. From figure 1, we can know that even when the reservoir conditions are more severe than the polymer block in Daqing, EOR per unit injection of SMG is higher than that of polymer flooding.

![Figure 1](image-url)

**Figure 1.** The scatter plot of EOR under unit injection for polymer and SMG

The ton oil cost of SMG Flooding in Liaohe oilfield, Qinghai oilfield, Changqing oilfield, North China and Dagang is $21.4, $22.57, $17.1, $15.27, $21.6. The average ton oil cost of the SMG flooding, $18.03, is less than half polymer flooding, which is $20.37 less than polymer flooding, $38.4. Therefore, The SMG flooding has the characteristics of low cost and good application effect.
6. Conclusion
In this paper, EOR per unit injection and barrel oil cost are used as evaluation indexes for the economic effect of SMG flooding and polymer flooding. The study has shown that the SMG flooding has the characteristics of low-cost and good application effect and the average ton oil cost of the SMG flooding is less than 50% the polymer flooding, even under extremely complex reservoir conditions. The SMG flooding provides a low-cost and efficient way to achieve “coming to life again for old oilfield”. The technology is very easy to replicate and popularize, which will further promote the efficient development of water-drive in petroleum industry.

7. References
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