Research Article

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Study on the adaptability of binary flooding in a certain oil field

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Abstract: To explore the synergistic mechanism of polymer and surfactant in the binary combination flooding of low-permeability reservoirs, the adaptability experiment of polymer salt-resistant partially hydrolyzed polyacrylamide and nonionic surfactant was carried out in the indoor system. Experiments at different ratios are also performed. The results show that the selected poly/surface binary flooding system increases with the concentration of polymer or surfactant, the viscosity of the poly/surface binary system also increases and, at the same time, has better temperature and salt resistance. The viscosity of the binary system will decrease when the salinity increases. When the surfactant concentration $CS = 0.2\%$ and the polymer concentration $CP = 0.2\%$, the viscosity of the system is the highest. The viscosity of the poly/table binary system at different concentrations decreases when the temperature rises: pure polymer ($CP = 0.2\%$), poly/table binary system displacement fluid $CP = 0.1\% + CS = 0.2\%$ and $CP = 0.2\% + CS = 0.2\%$; and the injection pressure first rises and then drops. The final recovery rate is 51.8%, which meets the development of most oil reservoirs.

Keywords: recovery ratio, polyacrylamide, surfactant, oil viscosity, polymer

1 Introduction

With the deepening of oilfield development [1], most of the oil reservoirs have entered the medium and high water cut development period. Conventional water injection development is faced with problems such as reduced efficiency and poor benefits. Research has shown that polymer and surfactant binary combination flooding can be used to further improve crude oil recovery [2]. Yield: when compared with the eastern oilfields, a certain oilfield has developed edge and bottom water [3], with a formation water salinity of 24,600 mg/L, permeability of $33.3 \times 10^{-3} \mu\text{m}^2$, and extremely poor permeability. The polymer in the poly/surface binary system is salt-tolerant [4]. The performance is poor; the viscosity of the system is low under the conditions of high salinity reservoirs [5]; it is easy to burst along the dominant seepage channel during the injection process; and the subsequent water flooding can easily break through the main slug and cause channeling [6]. Therefore, it is necessary to develop a new type of deep profile control and displacement agent, add a deep profile slug before the polymer/surface binary system flooding to improve the heterogeneity of the reservoir, and create a suitable reservoir environment for the polymer/surface binary flooding [7] to ensure the oil reservoir accumulation/surface binary flooding effect.

The mechanism of the poly/surface binary composite system to improve the oil displacement efficiency is that, on the one hand, it relies on the viscosity of the polymer solution to control the oil–water mobility ratio; on the other hand, it relies on the ultra-low interfacial tension generated by surfactants to capture and drive residual oil [8]. After the binary composite system is injected into the formation, chemical degradation will occur under reservoir conditions [9]. Therefore, the stability of the physical and chemical properties of the displacement agent itself is a prerequisite for ensuring its oil displacement effect [10]. The high-valent metal ions in the formation water affect the performance of the polymer solution [11]. During the production process of the oil field, due to the incompatibility of the injected water and other reasons, the salinity of the

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formation water and the produced water will continue to rise, especially for a certain oil reservoir [12]. The mineralization of some stratigraphic oil pools has reached 26,400 mg/L. Therefore, it is very important to study the influence of salinity on the viscosity of polymer solution [13]. After the polymer is injected into the oil layer, thermal degradation and further hydrolysis will occur under high-temperature conditions, which will destroy the stability of the polymer and greatly reduce the oil displacement effect of the polymer [14]. The oil-displacing agent should not only have a strong viscosity-increasing property but also have a good stability. Therefore, the investigation of the thermal stability of the poly/surface binary system is particularly important [15]. In this paper, under the condition of heterogeneous reservoir, three-layer heterogeneous core is used to compare and evaluate the oil displacement effect of polymer and surfactant mixed oil displacement system [16]. Combining with the commonly used chemical flooding methods in oilfields, indoor physical simulation experiments are used to systematically compare the flooding characteristics of individual polymer flooding and polymer/surface binary flooding and their potential for enhanced oil recovery [17]. The mixed system of polymer and surfactant is used in this paper, the swept volume can be expanded by polymer, the oil-water interfacial tension can be reduced by surfactant, so as to greatly improve oil recovery [18,19]. Advancement (sweep efficiency dominates), then the surfactant can fully contact more crude oil, exerts its low interfacial tension, emulsification solubilization, emulsification carry, and other oil displacement mechanisms, improving oil washing efficiency [20].

2 Experimental materials and main equipment

The experimental materials used are as follows: the polymer is salt-resistant partially hydrolyzed polyacrylamide, with a molecular weight of 12 million and a degree of hydrolysis of 30%; the surfactant code is 109PS985, which is a non-ionic surfactant with good temperature and salt resistance and is effective. The content is 40%, and the experimental water is simulated formation water with a salinity of 30,000 mg/L. For low- and high-permeability cores, the permeability is $20\text{--}25 \times 10^{-3} \mu\text{m}^2$ and $100\text{--}150 \times 10^{-3} \mu\text{m}^2$, respectively.

The main equipment used are as follows: magnetic stirrer (Shanghai INESA Scientific Instrument Co., Ltd.), MARS-III Rotary Rheometer (Haake Company, Germany), and DV-II Brookfield Viscometer. The apparent viscosity test ranges of various types of rotors are as follows: No. 0 rotor, 0–100 mPa s, speed 6 rpm; No. 1 rotor, 100–200 mPa s, speed 30 rpm; and No. 2 rotor, 200–1,000 mPa s, speed 30 rpm.

3 Rheological properties of the poly/surface binary composite system

In a room at 65°C, the poly/surface binary composite system was prepared, the experimental shear rate range is 0.1–1,000/s, a pre-shear of 170/s was applied for 3 min, and allowed to stand for 5 min to eliminate the influence of shear on the test and to pass the viscosity. In the retention rate test, a polymer with strong shear resistance and strong viscoelasticity is preferred.

The simulated formation water was used to prepare polymer solution and poly/surface binary composite system, where surfactant concentration $CS = 0, 0.1, \text{ and } 0.2\%$ and polymer concentration $CP = 0.1, 0.2, 0.3, 0.4, \text{ and } 0.5\%$. The rheological test results of the poly/table binary composite system are listed in Table 1.

The polymer concentration and the viscosity of the poly/table binary composite system have an influence. As the polymer concentration increases, the viscosity of the polymer solution and the poly/table binary system increases; the viscosity increases sharply when $CP = 0.4\%$. Under the same condition of polymer concentration, when the surfactant concentration increases, the viscosity also increases, indicating that the surfactant has a certain viscosity increasing effect. When the surfactant concentration $CS = 0.2\%$ and the polymer concentration $CP = 0.2\%$, the viscosity of the poly/table binary system before and after shearing is lower, and the viscosity retention rate is 41.3%.

The high-valent metal ions in the formation water affect the performance of the polymer solution. During the production process of the oil field, due to the incompatibility of the injected water and other reasons, the salinity of the formation water and the produced water will continue to rise, especially for a certain oil reservoir. The degree of chemistry has reached 26,400 mg/L. Therefore,

Table 1: Rheological measurement of the poly/table binary composite system

Surfactant concentration (CS), %		Viscosity under different polymer concentrations (CP), mPa s				
		CP = 0.1%	CP = 0.2%	CP = 0.3%	CP = 0.4%	CP = 0.5%
CS = 0	Before cutting	164.3	279.1	342.4	567.7	973.6
	After cutting	53.2	99.4	128.4	223.1	391.4
	Viscosity retention rate, %	32.4	35.6	37.5	39.3	40.2
CS = 0.1%	Before cutting	205.4	310.5	430.6	860.5	1,397
	After cutting	68.4	119.5	177.8	373.5	639.8
	Viscosity retention rate, %	33.3	38.5	41.3	43.4	45.8
CS = 0.2%	Before cutting	309.2	331.5	610.4	950.8	1621.2
	After cutting	108.8	136.9	265.5	443.1	776.6
	Viscosity retention rate, %	35.2	41.3	43.5	46.6	47.9

it is very important to study the influence of salinity on the viscosity of polymer solution.

4 Evaluation of salt tolerance of the poly/surface binary composite system

Polymer mother liquors at different concentrations were prepared, diluted with high-concentration saltwater to target polymer solutions with different salinity (10,000–40,000 mg/L), and stirred well, and the viscosity changes with salinity at 65°C were measured.

The simulated formation water was used to prepare polymer solution and poly/surface binary composite system when the surfactant concentration CS = 0.2% and the polymer concentration CP = 0.1 and 0.2%. The rheological test results of the poly/table binary composite system are listed in Table 2.

The viscosity of the poly/surface binary system at different concentrations decreases when the salinity increases, but the poly/surface binary system with a polymer concentration of 0.2% has a relatively high viscosity under high salinity. The viscosity of the pure polymer is not as high as that of the poly/table binary system with surfactants, and when the degree of salinity increases, the overall viscosity of the poly/table binary system is higher than that of the pure polymer solution. The viscosity of the poly/table binary system is larger than the viscosity of the single polymer; when the surfactant concentration CS = 0.2%, polymer concentration CP = 0.2%, the viscosity of the system is the highest, indicating that the poly/table binary system has good compatibility and synergy.

5 Evaluation of thermal stability of the poly/table binary composite system

The solution of the poly/surface binary flooding system was prepared with simulated injection water. After stirring evenly, the DV-II Brookfield viscometer was used to measure the initial viscosity; then, the two systems are packaged and placed in a 60–80°C oven for regular viscosity testing. The viscosity of the poly/table binary flooding system at different temperatures was obtained, and the thermal stability of the poly/table binary flooding system was evaluated.

The simulated formation water was used to prepare polymer solution and poly/surface binary composite system when the surfactant concentration CS = 0.2% and the polymer concentration CP = 0.1 and 0.2%. The rheological test results of the poly/table binary composite system are listed in Table 3.

The viscosity of the poly/table binary system at different concentrations decreases when the temperature increases, but the poly/table binary system with a polymer

Table 2: Evaluation of salt tolerance performance of the poly/table binary composite system

System ratio	Viscosity under different salinity (mg/L), mPa s			
	10,000	20,000	30,000	40,000
CP = 0.1%	164.3	138.9	94.4	56.8
CP = 0.2%	279.1	229.1	156.3	102.7
CP = 0.1% & CS = 0.2%	205.4	163.4	134.7	96.7
CP = 0.2% & CS = 0.2%	310.5	256.1	167.9	120.4

Table 3: Evaluation of thermal stability of the poly/table binary composite system

System ratio	Viscosity at different temperatures (°C), mPa s				
	60	65	70	75	80
CP = 0.1%	203.2	154.5	129.8	89.2	67.9
CP = 0.2%	297.4	232.4	219.3	138.3	100.2
CP = 0.1% + CS = 0.2%	220.7	205.4	187.4	146.3	102.5
CP = 0.2% + CS = 0.2%	325.6	310.5	258.6	215.8	185.3

concentration of 0.2% has a relatively higher viscosity than the concentration of 0.1% during the heating process. The viscosity of the poly/table binary system is greater than that of the polymer alone. When the surfactant CS = 0.2% and the polymer CP = 0.2%, the viscosity of the system is the highest, indicating that the poly/table binary system has good compatibility and synergy.

6 Oil displacement effect of polymer (0.2%) on cores with high and low permeability

Pure polymer (CP = 0.2%) was injected at an injection rate of 0.1 mL/min until the water content at the core outlet reaches 98%. During this period, the injection pressure, produced water, and produced oil volume are recorded, and the cores with different permeability are calculated. The recovery factor and water content are shown in Figures 1 and 2, respectively.

Figure 1: The oil displacement effect of 0.2% polymer on cores with low permeability.

It can be seen from Figure 1 that for low-permeability cores, with the increase of 0.2% polymer injection volume, the injection pressure first rises and then drops. The maximum injection pressure is 0.41 MPa and finally stabilizes at 0.22 MPa. When the water content is greater than 98%, the final recovery rate is 39.5%. For high-permeability cores, the injection pressure first rises and then drops. The maximum injection pressure is 0.52 MPa and finally stabilizes at 0.23 MPa. When the water content is greater than 98%, the final recovery factor is 45.0%.

7 The oil displacement effect of the poly/surface binary system (CP = 0.1% & CS = 0.2%) on cores with high and low permeability

The displacement fluid of the poly/surface binary system (CP = 0.1% + CS = 0.2%) was injected at an injection rate of 0.1 mL/min, the volume of produced fluid and produced oil were recorded. Until the water cut is stable at

Figure 2: The oil displacement effect of 0.2% polymer on cores with high permeability.

more than 98%; the injection pressure, produced water, and produced oil volume are recorded; and the recovery factor and recovery factor increase are calculated as shown in Figures 3 and 4.

As can be seen from Figures 3 and 4, for low-permeability cores, as the injection volume of the poly/surface binary system increases, the injection pressure first rises and then decreases. The maximum injection pressure is 0.55 MPa and finally stabilizes at 0.19 MPa. When the water content is greater than 98%, the final recovery rate is 47.5%. For high-permeability cores, the injection pressure first rises and then drops. The maximum injection pressure is 0.63 MPa and finally stabilizes at 0.30 MPa. When the water content is greater than 98%, the final recovery factor is 51.0%.

8 The oil displacement effect of the poly/surface binary system (CP = 0.2% & CS = 0.2%) on cores with high and low permeability

The displacement fluid of the poly/surface binary system (CP = 0.2% + CS = 0.2%) was injected at an injection rate of 0.1 mL/min, the volume of produced fluid and oil was recorded; water was injected at the same injection rate until the produced fluid. The water cut is stable at more than 98%; the injection pressure, the produced water, and the produced oil volume are recorded, and the increase in recovery factor is calculated as shown in Figures 5 and 6.

Figure 3: The oil displacement effect of the polymer/surface binary system on low-permeability cores.

Figure 4: The oil displacement effect of the polymer/surface binary system on high-permeability cores.

It can be seen from Figures 5 and 6 that for low-permeability cores, as the injection volume of the poly/surface binary system increases, the injection pressure first rises and then decreases. The maximum injection pressure is 0.55 MPa and finally stabilizes at 0.21 MPa. When the water content is greater than 98%, the final recovery rate is 48.7%. For high-permeability cores, the injection pressure first rises and then drops. The maximum injection pressure is 0.65 MPa and finally stabilizes at 0.35 MPa. When the water content is greater than 98%, the final recovery factor is 51.8%.

It can be seen from the above that within the selected permeability range, the enhanced oil recovery range of core binary flooding with higher permeability and subsequent water flooding also increases correspondingly. At the same time, the recovery ratio obtained by pure polymer flooding is far. It is much lower than the oil recovery

Figure 5: The oil displacement effect of the polymer/surface binary system on low-permeability cores.

Figure 6: The oil displacement effect of the polymer/surface binary system on high-permeability cores.

measured by the binary system, indicating that the binary system has good mobility control and oil washing effects.

9 Conclusion

- (1) The polymer in the selected poly/surface binary flooding system is salt-resistant partially hydrolyzed polyacrylamide, with a molecular weight of 12 million, a degree of hydrolysis of 30%, and a polymer concentration of $CP = 0.2\%$; the surfactant is “109PS985”, which is non-ionic. The type of surfactant has good temperature resistance and salt resistance. The surfactant concentration CS is 0.2% , and the experimental water is simulated formation water with a salinity of 30,000 mg/L.
- (2) When the surfactant concentration $CS = 0.2\%$ and the polymer concentration $CP = 0.2\%$, the viscosity retention rate is 41.3%. The viscosity of the poly/table binary system with different concentrations will decrease when the salinity increases. When the surfactant $CS = 0.2\%$ and the polymer $CP = 0.2\%$, the viscosity of the system is the highest. The viscosity of the poly/table binary system at different concentrations decreases when the temperature increases. When the surfactant $CS = 0.2\%$ and the polymer $CP = 0.2\%$, the viscosity of the system is the highest.
- (3) The oil displacement performance of the three systems was evaluated, pure polymer ($CP = 0.2\%$), poly/surface binary system displacement fluid $CP = 0.1\% + CS = 0.2\%$ and $CP = 0.2\% + CS = 0.2\%$, when surfactant $CS = 0.2\%$, polymer $CP = 0.2\%$, the injection pressure increases first and then decreases, and the final recovery factor is

51.8%. It has the best performance and is suitable for oilfield production.

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