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The performance evaluation of nano-micron microsphere for profile control and displacement agent in low permeability reservoir

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Abstract. At present the waterflood efficiency is lower in most low permeable heterogeneous reservoirs, and the effect is poor using common polymer as profile control and displacement agent. As a new agent for profile control and displacement, the flow behavior of the nano-micron microsphere is evaluated in laboratory in this paper. The experimental result shows that it has well injectivity and flowability when flowing through the low permeability core. Because the nano-micron microsphere has a behavior of gradual expansion, it can be able to decrease permeability of porous medium very well. Especially in the process of subsequent water injection, the injection pressure increases firstly and then appears a small fluctuation declining, which shows that nano-micron microsphere solution has better antiscour performance and ability of gradual controlling and sealing.

1. Introduction

During waterflood process of low-permeability oilfield, the factors including oil-water viscosity difference, reservoir plane and vertical heterogeneity and others result in water breakthrough along high permeable layers, so that low permeable layers can not or poorly be developed, and the waterflood efficiency is seriously affected [1-4]. Therefore, the technology of the deep displacement used in low permeability oilfield is put forward [5-6] in order to weaken the heterogeneity of reservoir, enlarge the swept volume and improve waterflood effect in low permeability oilfield at high water-cut late stage [7-8].

However, the effect of the profile control and displacement agent that used commonly in the low-permeability oilfield is poor [9]. For example, the crosslinking controllability of movable weak gel as profile control and flooding is poor, and the cost is higher. LPS flooding control system is easy to be influenced by wastewater quality. Swellable particulate gel as profile control and flooding agent is so large that there exists contradiction between the injection depth and sealing strength, resulting in losing efficacy quickly in low permeable layers. Inorganic sealing agent is easy to precipitate, and can not enter into the indepth layer to plug [10-13]. In view of these problems, a new type of profile control and flooding agent with nano-micron microsphere is applied to achieve better effects [14-18].

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In this paper, the flowability and antiscour performance in low permeability core have been studied in the laboratory by the measurement of resistance factor and residual resistance factor of nano-micron microsphere solution and subsequent injection pressure in this flowing test. This research result can provide a reference for the application of this new profile control and flooding agent with nano-micron microsphere in low-permeability oilfield.

2. Experimental

2.1. Experimental conditions

The effective permeability of the rectangular homogeneous artificial core used in the experiment is $20\times10^{-3}\mu m^2$, $50\times10^{-3}\mu m^2$, $80\times10^{-3}\mu m^2$, $100\times10^{-3}\mu m^2$ and $200\times10^{-3}\mu m^2$ respectively. The concentration of nano-micron microsphere solution is 2000mg/L, 3000mg/L and 4500mg/L respectively, and viscosity is 0.91mPa·s, 0.92mPa·s and 0.96mPa·s respectively. The water used in saturating core is synthetic simulated formation brine that degree of mineralization is 8230.2mg/L, and the water used in core displacement test is advanced treated sewage that degree of mineralization is 6495.15mg/L. The experimental temperature is at 47.5ºC (reservoir temperature).Experiment equipment includes thermostat, constant pressure and speed pump, high-pressure vessel, manual measuring pump, produced liquid meterrun, vacuum pump, pressure gauge, etc.

2.2. Experimental procedure

①Put rectangular cores with different permeability in core holder, add 5 MPa ring pressure, vacuumize cores and continue for 6h, saturate synthetic brine, and then measure porosity; ②Put rectangular cores saturated synthetic brine in an thermostat of 47.5℃ for more than 12h, and then measure its permeability to water, the measurements are shown in Table 1; ③Inject the advanced treated sewage at the rate of 0.3ml/min before the pressure difference has been stable, then record the pressure difference (ΔPwi) at the two side of the core; ④Respectively inject the different concentrations(2000mg/L、3000mg/L and 4500mg/L) of nano-micron microsphere solution at the rate of 0.3ml/min(calculated according to the frontal velocity of Daqing oilfield) before the pressure difference has been stable, then record the pressure difference (ΔPm) at the two side of the core; ⑤ Repeat the third step, and then record the pressure difference (ΔPwa) at the two side of the core; ⑥ Continue to inject the advanced treated sewage, observe the pressure changes constantly, and then record the stable pressure difference.

Table 1. Basic parameters and experimental scheme of rectangular homogeneous core.

Core number	length (cm)	area (cm^2)	porosity (%)	permeability ($10^{-3}\mu m^2$)	Experimental scheme (Concentration of injected nano-micron microsphere solution)
JZA-1	30.26	20.39	19.18	20.13	
JZA-2	30.39	20.13	19.48	48.53	
JZA-3	30.15	20.18	19.25	78.14	2000mg/L
JZA-4	30.30	20.28	17.93	100.32	
JZA-5	30.26	20.13	17.46	201.25	
JZB-1	30.25	20.14	17.76	21.24	
JZB-1	30.25	20.26	26.38	49.26	
JZB-1	30.28	20.17	26.42	83.42	3000mg/L
JZB-1	30.20	20.16	26.15	105.38	
JZB-1	30.22	20.10	27.42	210.2	
JZC-1	30.22	20.26	27.34	19.8	
JZC-1	30.18	20.16	27.35	48.94	
JZC-1	30.24	20.19	20.12	85.52	4000mg/L
JZC-1	30.26	20.24	20.34	102.64	
JZC-1	30.18	20.20	20.48	201.52	

3. Results and Discussion

According to the experiment results, a relationship curve is established between resistance factor and permeability (Figure 1.), and a relationship curve is also established between residual resistance factor and permeability (Figure 2.).

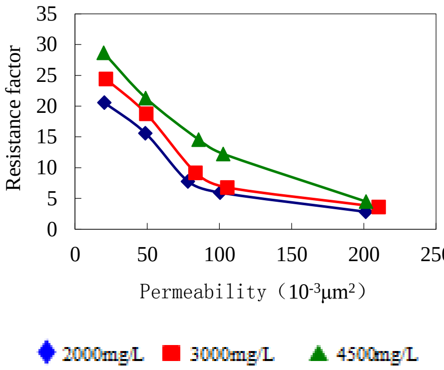


Figure 1. Curves of resistance factor with permeability.

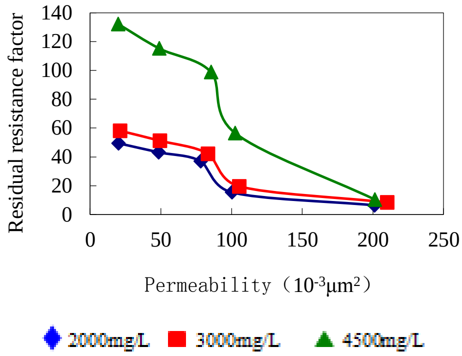
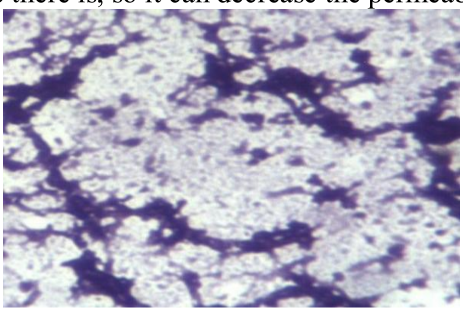


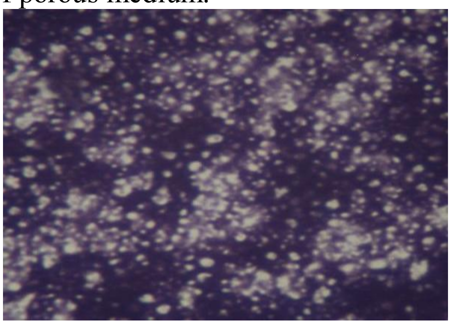
Figure 2. Curves of Residual resistance factor with permeability.

There are three curves of resistance factor with permeability in Figure 1, which depict three concentrations of nano-micron microsphere solution (2000mg/L, 3000mg/L, 4500mg/L), respectively. According to the three curves of Figure 1, the regularity can be seen that the higher the concentration of nano-micron microsphere solution the greater the resistance factor when the permeability is kept constant. This shows that the injectivity of high concentration of nano-micron microsphere solution is worse than that of low concentration in low permeability core. When low concentration of nano-micron microsphere solution (2000mg/L) is respectively injected into core samples with permeability from low to high, the resistance factor varies from 20 to 3. This shows that it has good injectivity and flowability not only in medium to high permeability core but also in low permeability core ($20\times10^{-3}\mu m^2$).

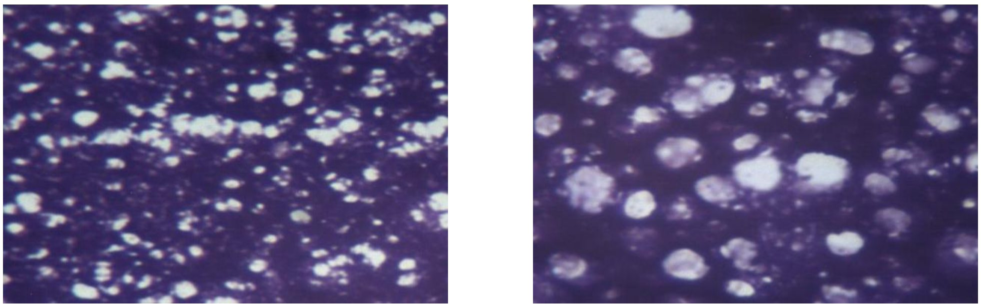
There are three curves of residual resistance factor with permeability in Figure 2, which depict three concentrations of nano-micron microsphere solution (2000mg/L, 3000mg/L, 4500mg/L), respectively. According to the three curves of Figure 2, the regularity can be seen that residual resistance factor decreases with the increase of the permeability. This shows that the sealing effect in low permeability cores is better than medium to high permeability cores. In low permeability cores, the residual resistance factor of high concentration of nano-micron microsphere solution (4500mg/L) is much greater than that of low concentration(2000mg/L or 3000mg/L), it is because that the nano-micron microsphere has gradual expansibility in solution, which can be seen in Figure 3. In the injection process, single-particle is continuous swelling and there is continuous mutual adsorption and accumulation among many particles, which is called hydration expansion of nano-micron microsphere. The higher the concentration is, the more possibility of sealing caused by more aggregate and adsorbate there is, so it can decrease the permeability of porous medium.



(a)1d



(b)5d



(c)10d (d)20d

Figure 3. Expansion variation of Nano-micron microsphere solution (2000mg/L) within 20 days under microscope.

After measuring residual resistance factor, water injection is continued to enter into the core and that pressure differences vary with injection pore volume multiple is measured, so as to evaluate the antiscour performance of nano-micron microsphere. With a low-permeability core called JZA-1 as example, the change of pressure with injection volume can be seen in Figure 4. Because of continuous hydration expansion in the injection process, part of porous channel is plugged by aggregate and adsorbate, which results in gradual rising of pressure. In the subsequent injection process, there are so many particles of nano-micron microsphere adsorbing and accumulating in the pore throat that the pressure increases further. After the pressure reaches a certain value, the nano-micron microspheres can pass the pore throat because of the compressive deformation. When it move to the deeper under the pushing of subsequent water, the pressure decreases. There are so many pore throats in the process of the following migration that the phenomena including the above process can appear continuously. The pressure increases firstly and then decreases in the process of experiment that subsequent water injection volume is 4.5PV. The experimental results showed that the nano-micron microsphere solution has better antiscour performance as well as the ability of gradual controlling and sealing in the low permeability layer.

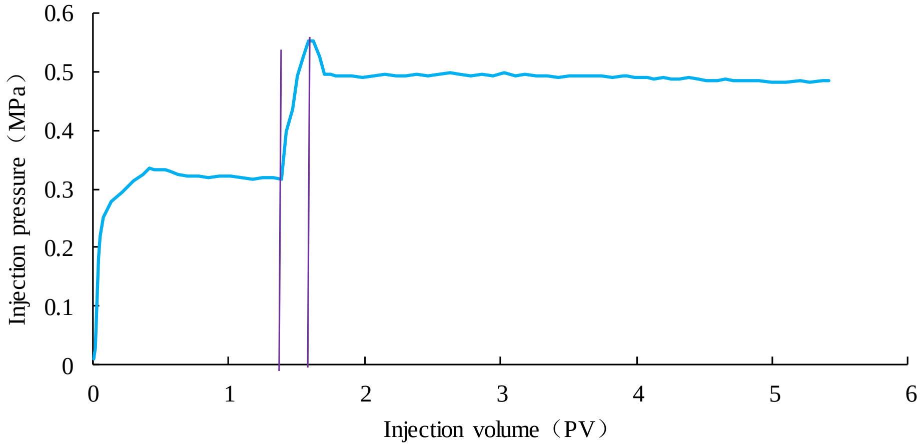


Figure 4. Curve of pressure with injection volume of Nano-micron microsphere (2000mg/L) through JZA-1 core.

4. Conclusions

- The resistance factor of nano-micron microsphere solution is low (20 or so) in low permeability cores, which shows that it has better injectivity and flowability in low permeability cores.
- Because of continuous hydration expansion in the injection process, part of porous channel is plugged by aggregate and adsorbate, which results in gradual rising of the pressure and residual

resistance factor becoming bigger. This shows that nano-micron microsphere solution has better ability to decrease permeability of porous medium.

- After injecting nano-micron microsphere solution in low permeability core ($20\times10^{-3}\mu m^2$), the pressure increases firstly and then appears a small fluctuation declining in the subsequent water injection. This shows that the nano-micron microsphere solution has better antiscour performance as well as the ability of gradual controlling and sealing in the low permeable medium.

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