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Flow Characteristic of Aqueous Dispersion System of Nano/micron-sized Polymer Particles Through Microporous Membrane

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Abstract: In order to evaluate percolation ability of aqueous dispersion system of nano/micron-sized polymer particles in porous media, the flow characteristic and its influence factors were studied by laser particle size analyzer and filtration device of microporous membranes which were simulated to reservoir pore throat. The results show that at the same hydration time, plugging capacities of nano/micron-sized polymer particles gradually increase as their average particle sizes increase; at the different hydration time, plugging capacities of nano/micron-sized polymer particles show a trend of increasing first and then decreasing with increasing average particle sizes. With increasing pressure differentials, the plugging capacities of nano/micron-sized polymer particles gradually decrease and their deep profile control capacities gradually increase. When pore sizes of microporous membrane decrease, the plugging capacities of nano/micron-sized polymer particles rapidly increase and their deep profile control capacities quickly decrease. When the particle concentrations increase, the plugging capacities of nano/micron-sized polymer particles increase and their deep profile control capacities decrease.

Key words: Nano/micron-sized polymer particles, microporous membrane, flow characteristic, plugging, deep profile control

INTRODUCTION

In recent years, a new type of deep reservoir flooding water plugging technology-Nano/micron-sized polymer technology, has been developed as a new method to improve the effectiveness of low permeability oilfield development (Hou *et al*., 2008; Yin *et al*., 2005). The technology relies on the nano/micron-sized polymer particles which are water swellable to plug formation pore throats step by step to achieve its deep profile control capacities (Zhao *et al*., 2009; Wever *et al*., 2011; Liu *et al*., 2012). Currently, many scholars at home and abroad prepared different types of nano/micron-sized polymer particles with different synthesis methods. As the preparation methods and specific components are different, their plugging capacities are also different. Cui and Dong (2007) and some other researchers prepared microballoon and simulate oil deposit conditions for the evaluation of the applicability of microballoon through Reversed-phase microemulsion method. Han *et al*. (2008) made a research on the plugging capacities and influence factors of the dispersion system of cross-linked polymer microballoon that synthetized by Cui's team. Zhao *et al*. (2005) also made a research and evaluation on the plugging capacities of the water soluble cross-linked polymer microballoon. Most of the nano/micron-sized polymer particles are prepared by adopting the reversed-phase microemulsion method (Wang *et al*., 2006; Zhu *et al*., 2006; Hou, 2007). However, the author uses distillation precipitation polymerization method to prepare the acrylamide copolymer composite particles (Li *et al*., 2012)which is different from the reversed-phase microemulsion method in plugging capacities. To represent its percolation ability in porous media, the author uses filtration device of microporous membranes to simulate reservoir pore throat and uses laser particle size analyzer and filtration device of microporous membranes to study the flow characteristic and its influence factors.

EXPERIMENT

Reagent and Instrument: Acrylamide copolymer composite particles; Sodium chloride, potassium chloride,

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sodium sulfate, sodium carbonate, sodium bicarbonate, magnesium chloride, calcium chloride, sodium hydroxide and hydrochloric acid are all analytical reagent. Deionized water made in the laboratory was filtered by cellulose acetate microporous membrane. THZ-C thermostatic oscillator made by Beijing Cheng Meng Technology Co., Ltd; MasterSizer2000 laser particle size analyzer, produced by Malvern, UK production company, using He-Ne light source, laser power supply power 10 mw, detection wavelength was 633nm, instrument test range 0.02~2000 8m, measuring temperature is 25 °C; LC-20AT-type liquid chromatograph infusion pumps, produced by Shimadzu Corporation; BSA1245 electronic scale, produced by the German sartorius; polycarbonate membrane filter with the diameter of 0.45, 0.8, 1.2, 2.0 and 3.0 μm; Filtration device of microporous membranes consists of constant pressure pumps, precision pressure gauges, intermediate container, porous medium equipment, electronic balance and automatic data acquisition system structure. Experimental setup process is shown in Fig. 1. The intermediate containers, porous medium equipment and an electronic balance is placed in incubator.

Experimental methods: Analyze the capabilities of polymer particles to pass through porous media which were simulated to reservoir pore throat and then evaluate its plugging capacities. Prepare dispersion solution of polymer particles with different concentration and different particle size under different differential pressure by using polymer composite particle filter and microporous membranes. And then the solution is passed through microporous membranes. The time spent in filtering each 2.5 mL particle disperse system is recorded until the 22.5 mL dispersion solution was filtered. Draw curves of the relation of filtration volume and filtration time under different conditions and analyze the influence of hydration time, pressure differential, membrane pore size, particle size and particle concentration on the plugging capacities.

Experimental results and analysis

The influence of hydration time on flow characteristic: When the differential pressure is 0.1MPa, hydrate polymer particle dispersion system of NaCl with the concentration of 1.5 g L^{-1} at 60 °C. The relationship between filtration volume and filtration time after filtering through the microporous membrane of 1.2 μm at different time is shown in Fig. 2.

Figure 2 shows that for polymer particles with fixed hydration time with the increase of filter volume, the time spent in filtering the 2.5 mL polymer particle dispersion system increases. It indicates that polymer particles of different hydration time all make a contribution to the plugging of the microporous membranes of 1.2 μm. Besides with the increase of the filtration volume, the plugging effect on the subsequent flow increases. When filtering the polymer particle dispersion system with the same volume with the increases of hydration time, the filtration time first increases and then decreases.

Influence of hydration time on its filtration time is shown in Fig 3. Figure 3 shows that when filter any polymer particle dispersion system of the same volume with the increases of the hydration time, filtration rate first began to decrease until hydration time reaches 120 h when filtration rate reaches a minimum. Then the filtration rate gradually increases. It indicates that with the increase of the hydration time, the particles swell in aqueous solution and the particle size increases. Therefore, the plugging effect of particles on 1.2 μm microporous

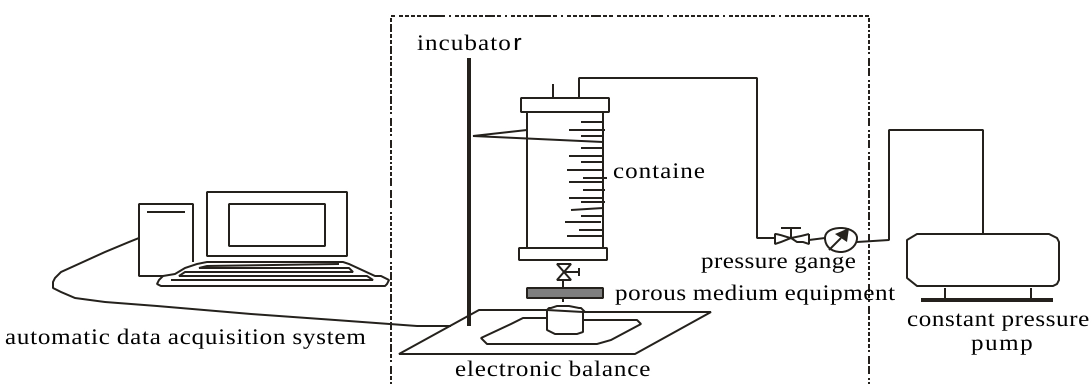

Fig. 1: Experimental setup flow chart of microporous membrane

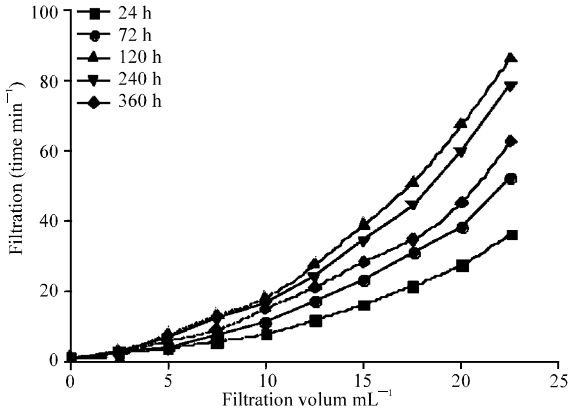

Fig. 2: Relation curve of filtration volume and filtration time at different hydration time

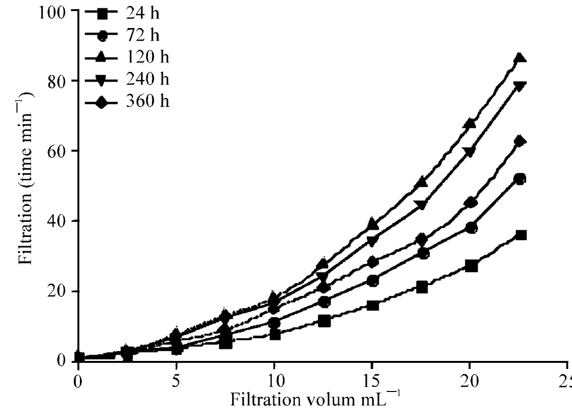

Fig. 4: Relation curve between the filtration volume and filtration time under different pressure

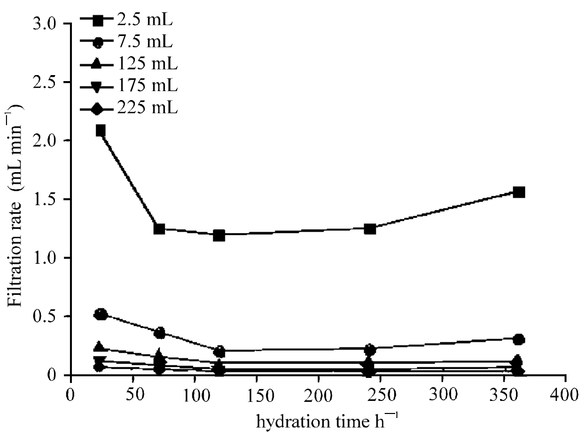

Fig. 3: Influence of hydration time on the filtration ratewith different filtration volume

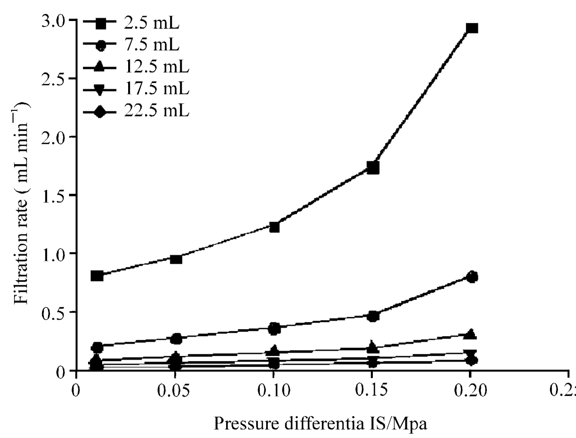

Fig. 5: Influence of pressure differentials on filtration rate with different filtration volume

membrane gradually increased. The particles hydrated for 120 h have the optimal plugging capacities. But after the hydration of 120 h, as the particles are hydrated for a long time, particles have better deformability with the increase of particle size which makes it easier for particles to pass through the microporous membrane and make the plugging capacities decrease. It can be seen that although the polymer particles are able to plug the pore throat effectively, at the same time, another part of polymer particles can pass through the pore throat by deformation to achieve profile control capacities.

Influence of pressure differentials on flow characteristic: With the temperature of 60 °C, after the polymer particle dispersion system with the hydration of 72 h, concentration of 1.5 g L^{-1}, NaCl concentration of 5g L^{-1} pass through the microporous membrane of 1.2 μm, the relationship between filtration volume and filtration time is shown in Fig. 4.

Figure 4 shows that, under different pressure with the increase of the filtration volume, the time spent in filtering 2.5 mL particle dispersion system increases. It shows that particle dispersion system all form plugging on the microporous membrane of 1.2 μm. Besides with the increase of pressure differentials, the time spent in filtering the polymer particle dispersion system of the same volume decreases.

The influence of pressure differentials on filtration rate is shown in Fig. 5. Figure 5 shows that in filtering any polymer particle dispersion system of the same volume, as the pressure difference increases, the filtration rate is gradually increasing. It indicates that under high pressure, the polymer particles are more likely to rely on deformation to pass through pore throat when in the situation of a certain plugging. The greater the pressure differentials, the smaller the pore throat they can pass through which is benefit for polymer particle dispersion system to achieve its profile control capacities. However, under low pressure, the time polymer particles plugging in the microporous membrane increases and the plugging capacities increase. The longer time in the plugging is benefit for the move the subsequent flow and the expansion the volumetric sweep efficiency. Therefore it is very significant to choose a proper injection pressure differential for polymer particle dispersion system to achieve more efficient profile control capacities.

Influence of microporous membrane pore size on flow characteristic: When the differential pressure is 0.1MPa, after the polymer particle dispersion system with the hydration of 72 h, concentration of 1.5 g L^{-1}, NaCl concentration of 5 g L^{-1} pass through the microporous membrane of different pore sizes, the relationship between filtration volume and filtration time is shown in Fig. 6.

Figure 6 shows that in a microporous membrane with different pore sizes with the increase of filtration volume, the time used in filtering 2.5 mL polymer particle dispersion system increases gradually. It indicates that polymer particle dispersion system form plugging on microporous membrane of different pore sizes but the plugging capacities vary. With the increase of microporous membrane pore size, the time used in filtering the polymer particle dispersion system of the same volume decreases drastically.

The influence of microporous membrane pore size on filtration rate is shown in Fig. 7.

Figure 7 shows that when filtering the polymer particle dispersion system of the same volume with the increase of the microporous membrane pore size, the particles pass through the membrane pore mainly by deformation for the distribution of polymer particle size. At this time, a large number of polymer particles plug at the membrane pore and only a small amount of polymer particles pass through by deformation which makes the filtration rate decrease drastically. Therefore, we can consider that this particle dispersion system have strong plugging capacities on the microporous membrane of 0.45 μm rather than profile control capacities. With the increase of microporous membrane pore size, the filtration rate increases drastically which indicates that on the membrane pore of 3.0 μm, the particles mainly pass through directly and only a small part of particles pass through by deformation. The plugging capacities are relatively weak and most particles which have passed through may plug, delay or pass through in the subsequent reservoir. We can see that only when the injected polymer particles and reservoir match with each other can they have effective plugging capacities as well as profile control capacities.

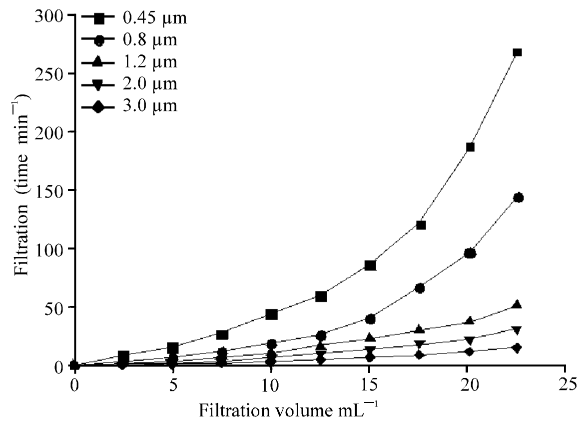

Fig. 6: Relation curve between the filtration volume and filtration time with different microporous membrane pore size

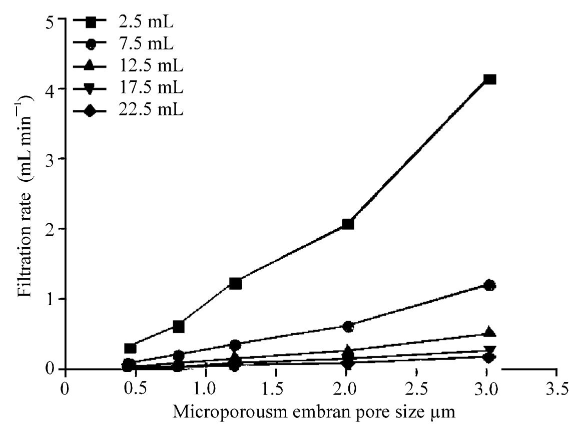

Fig. 7: Influence of microporous membrane pore size on filtration rate with different filtration volume

Influence of particle size on flow characteristic: Chang the polymer particles synthesis conditions and obtain polymer particles with initial particle size distribution. And then prepare polymer particle dispersion system with the concentration of 1.5 g L^{-1}, NaCl concentration of 5 g L^{-1}. Hydrating the particles of the average particle size of 1.13′ 1.24′1.68′1.83 and 1.97 μm in the water of 60°C for 72 h. Under 0.1MPa pressure differentials, pass these polymer particles through microporous membrane of 1.2 μm and then we can get the relationship between filtration volume and filtration time as shown in Fig. 8.

Figure 8 shows that for different initial size distribution of the polymer particle dispersion system with the increase of filtration volume, the average time used in filtering 2.5 mL polymer particle dispersion system increases which indicates that polymer particle dispersion system with different initial particle sizes all form plugging

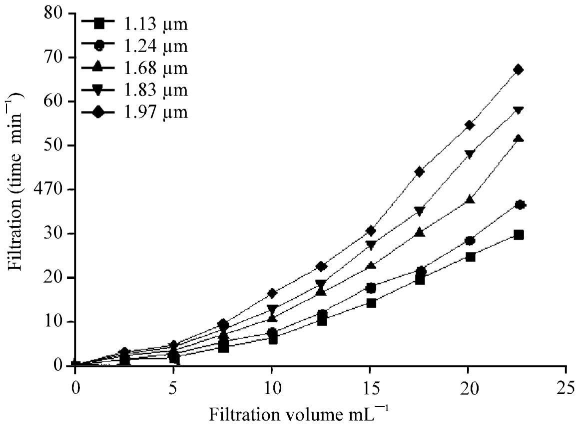

Fig. 8: Relation curve between the filtration volume and filtration time with different particle sizes

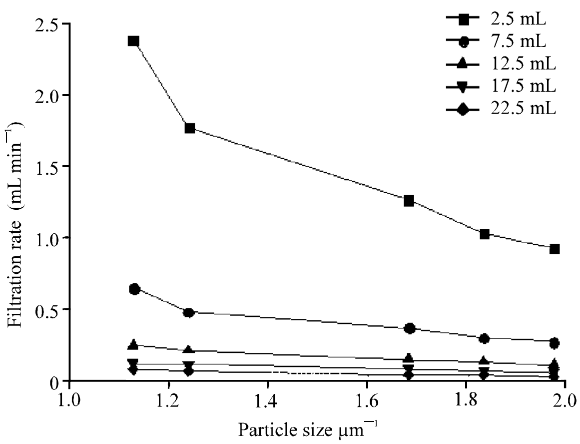

Fig. 9: Influence of particle size on filtration rate with different filtration volume

on the microporous membrane of 1.2 μm. What's more with the increase of the average particle size, the time used in filtering polymer particle dispersion system of the same volume increases.

The influence of microporous membrane pore size on filtration rate is shown in Fig. 9. Figure 9 shows that in the filtration of the polymer particle dispersion system of the same volume with the increase of the particle size, the filtration rate decreases which indicates that with the increase of the polymer particle size, the plugging capacities on the microporous membrane of 1.2 μm become stronger and the capacities to pass through the microporous membrane become weaker. This result is different from the experiment using polymer particle dispersion system with the same initial particle size but hydrated with different days, indicating that the deformation ability is related to hydration time. When the hydration time is less than 120 h, for the polymer particles

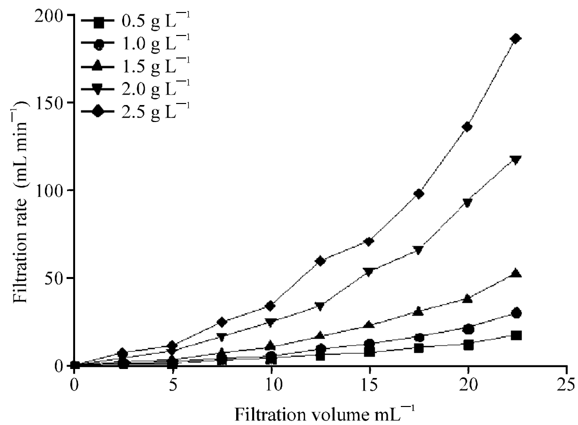

Fig. 10: Relation curve between the filtration volume and filtration time with different particle concentration

with large particle size it is not enough, so the deformation ability is weak and it is hard to pass through the microporous membrane of 1.2 μm; When the hydration time is more than 120 h with the increase of hydration time, the polymer particles are fully hydrated and the deformation ability increases, so their ability to pass through the microporous membrane of 1.2 μm become stronger. For the polymer particle dispersion system hydrated for the same time span, the larger the particle size, the harder it is to pass through the microporous membrane of 1.2 μm, the stronger the plugging capacities and the lower the hydration rate.

Influence of particle concentration on flow characteristic: Prepare the polymer particle dispersion system of different concentrations by using saline water with the NaCl concentration of 5g L^{-1} and hydrate in the water of 60°C for 72 h under the pressure of 0.1MPa. And then pass these polymer particles through the microporous membrane of 1.2 μm. We can obtain the relationship between the filtration volume and filtration time as shown in Fig. 10.

We can know from Fig. 10 that for polymer particle dispersion systems of different concentration with the increase of filtration volume, the time used in filtering the particle dispersion system of 2.5 mL increases, indicating that polymer particle dispersion systems of different initial particle size all form plugging on the microporous membrane of 1.2 μm. Besides with the increase of particle concentration, the time spent in filtering the polymer particle dispersion system of the same volume increases.

The influence of particle concentration on filtration rate can be seen in Fig. 11. The Figure 11 shows that when filtering the polymer particle dispersion system of the same volume with the increase of particle concentration,

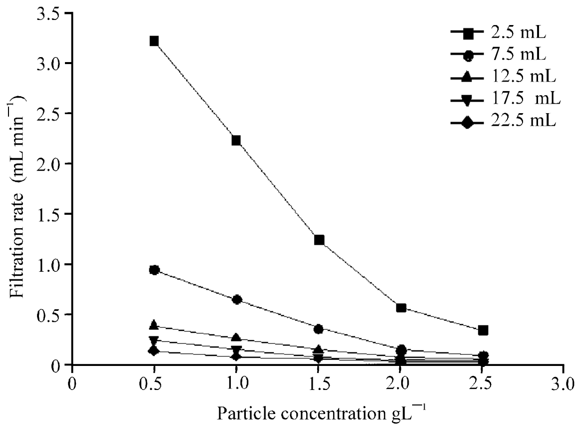

Fig. 11: Influence of particle concentration on filtration rate with different filtration volume

the filtration rate decreases drastically which indicates that with the increase of particle number in the dispersion system, the plugging capacities of microporous membrane of 1.2 μm on the polymer particles become stronger and the ability of polymer particles to pass the microporous membrane become weaker because in the dispersion system of high concentration, the number of particles in the unit volume increases and the distance among the particles become shorter. Thus the particles are easier to absorb bridging and delay. The higher the particle concentration, the more particles are absorbed which is reflected in the drastic decrease of filtration rate with the increase of particle concentration (Ma *et al*., 2006; Li *et al*., 2008).

CONCLUSION

- At the same hydration time, plugging capacities of nano/micron-sized polymer particles gradually increase as their average particle sizes increase; At the different hydration time, plugging capacities of nano/micron-sized polymer particles show a trend of increasing first and then decreasing with increasing average particle sizes. The increase of the hydration time helps to form effective plugging capacities and achieve deep profile control capacities of the storage of polymer particles
- With increasing pressure differentials, the ability to pass through the pore throat increases, the plugging capacities of nano/micron-sized polymer particles gradually decrease and their deep profile control capacities gradually increase. When pore sizes of microporous membrane decrease, the filtration rate of filtering the particle dispersion system of the same volume decreases drastically, the plugging capacities of nano/micron-sized polymer particles rapidly increase and their deep profile control capacities quickly decrease
- When the particle concentrations increase, the plugging capacities of nano/micron-sized polymer particles increase, the abilities to pass through the pore throat decrease and their deep profile control capacities decrease

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