A novel nano-sized polymer microsphere as a potential shale stabilizer in water-based drilling fluids

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ABSTRACT

Borehole instability caused by pore pressure transmission and shale hydration gives rise to a number of problems, which has been a challenge during oil and gas drilling process for many years. In this paper, a novel nano-sized polymer microsphere as a potential shale stabilizer in water-based drilling fluids for drilling troublesome shale formations was successfully synthesized and characterized. Its shale inhibition characteristic was investigated with hot-rolling cuttings dispersion test and linear swelling test. The results indicated that it had good performance to prevent shale hydration. In addition, pressure transmission test was carried out to evaluate the sealing performance of the prepared polymer microsphere. The nano-sized polymer microsphere could effectively retard pore pressure transmission and reduce the permeability of shale samples. Hence, the prepared novel nano-sized polymer microsphere may be a potential stabilizer in the water-based drilling fluids for drilling troublesome shale formations.

Keywords: nano-sized polymer microsphere, water-based drilling fluids, shale formations, shale hydration, pressure transmission

1 INTRODUCTION

Drilling fluids play a vital role in the field of oil and gas drilling. Recently, the development and utilization of shale gas have attracted much attention. However, wellbore instability often occurs in the drilling process of shale formations [1]. How to solve the wellbore instability problems is the focus the researchers concerned. Recent research shows that retarding pore pressure transmission is the key method to solve the problem [2]. However, the conventional plugging agents are not effective for plugging the shale pores because the sizes of shale pores are in nanometer range. Combining nanotechnology with drilling fluids may be a new way to solve the problem.

In recent years, more and more attention has been paid to the application of nano materials in drilling fluids [3]. Non-modified silica nanoparticles were first introduced into drilling fluids. Research showed that they could plug the pore throats of shale, thus reducing the permeability of shale formations [4]. But the agglomeration behavior of silica nanoparticles is very prominent so that their application in the drilling fluids is restricted. The polymer microsphere prepared by emulsion polymerization has good dispersibility in drilling fluids due to the addition of emulsifier. Therefore， exploring the application of polymer microsphere in drilling fluids may be a new approach to solve shale instability problems. Moreover, shale hydration is also an important factor causing shale instability [5]. Certain polymeric monomers can help ehance the shale inhibition property. Thus, it is a meaningful work to introduce the polymer microsphere into the drilling fluids for solving shale instability problems.

2 SYNTHESIS OF POLYMER MICROSPHERE

Emulsion polymeration was adopted to prepare the polymer microsphere, which was conducted in a four-necked flask. In general, a certain amount of styrene (St), n-butyl acrylate (BA) and acrylic acid (AA) monomers were dispersed in deionized water, in which the emulsifiers SDS and OP-10 were dissolved. And a certain amount of sodium bicarbonate ($NaHCO_3$) were added into the system as a buffering agent. Then they were stirred in the flask and the temperature was kept at 80 ℃. After stirred for 30 minutes, the polymerization was induced by the initiator potassium persulfate (KPS). Another 3.5 hours was needed to complete the polymerization.

3 CHARACTERIZATION AND PROPERTISE

Transmission Electron Microscopy (TEM) was used to study the dispersing morphology of the polymer microsphere. Particle size distribution (PSD) of the polymer microsphere was analyzed with Zetasizer Nano ZS90. Thermal gravimetric analysis (TGA) was conducted on a TGA/DSC1 thermal analyzer.

3.1 TEM

The TEM image of the prepared polymer microsphere is presented in Fig. 1. It could be seen that the prepared polymer microsphere has good dispersion in aqueous solution and the microsphere has regular shape (mainly spherical). Through the image, the microsphere has uniform particle size (about 85 nm).

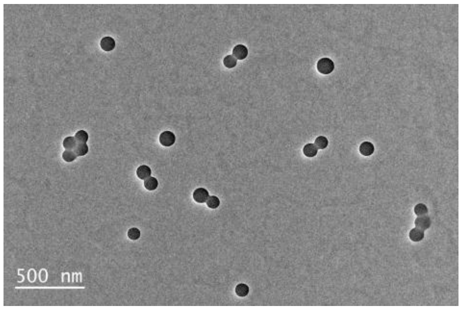

Fig. 1. The TEM image of polymer microsphere.

3.2 PSD

Fig. 2 shows the particle size distribution (PSD) of the prepared polymer microsphere. It can be seen that the particle size of the prepared polymer microsphere ranged from 50 nm to 190 nm and the medium particle size D50 was 88 nm. The particle size distribution was narrow with 62 nm for the D10 value and 129 nm for the D90 value. The test results were coincided with the test results of TEM analysis.

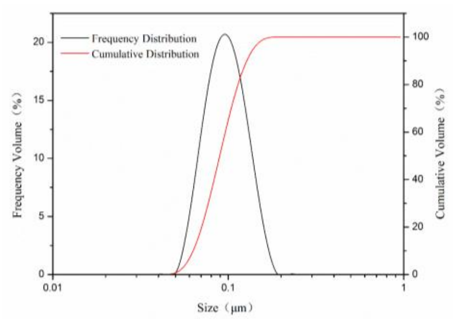

Fig. 2. The PSD curves of polymer microsphere.

3.3 TGA

Thermal stability is a key performance for drilling fluid agent. Fig. 3 presents the TGA curve of the prepared polymer microsphere. It can be seen that the weight loss of the polymer microsphere was not obvious until the emperature was increased to 375 ℃. Thus, the prepared nano-sized polymer microsphere had good thermal stability.

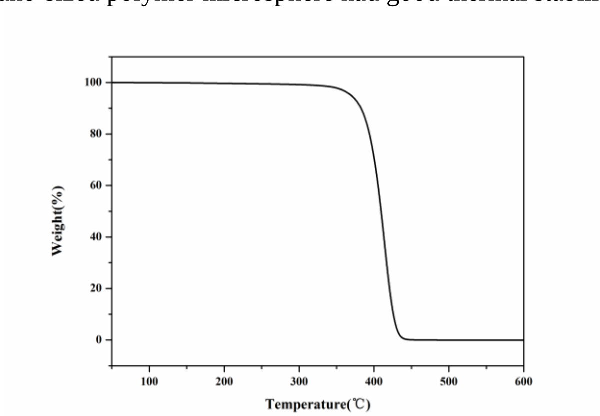

Fig. 3. The TGA curve of polymer microsphere.

3.4 Hot-rolling cuttings dispersion test

The hot-rolling cuttings dispersion test was conducted to evaluate the inhibition performance of the prepared polymer microsphere. The higher recovery rate indicated the better shale inhibition performance. Inorganic salts (KCl) and polymeric alcohol (JHC) as two common used shale inhibitors were chosen to compare with the prepared polymer microsphere. In brief, 50g of shale samples with sizes between 6 and 10 mesh were put into the ageing can, which contained 350 mL testing fluid. Then, they were placed into a XGRL-4 type rolling oven (Haitongda Company, China) to be hot rolled at 77 ℃ for 16 hours. After hot rolled, a 40 mesh sieve was used to collect the remaining shale samples. Finally, the samples were washed with tap water and oven-dried at 105 ℃ for 4 hours. The recovery rate could be calculated through the measured weight of the recovered shale samples.

Fig. 4 shows the test results of hot-rolling cuttings dispersion test. The recovery rate of shale samples in tap water was 40.2%, indicating that the hydration dispersion capacity of the shale samples was strong. The shale hydration and dispersion inhibition capacity of polymer microsphere was much better than frequently used shale inhibitors KCl and JHC. Under different concentrations, the recovery rate of polymer microsphere was higher than KCl and JHC. Eespecially, at the concentration of 2%, the recovery rate of polymer microsphere was 93.7% and it was 2.33 times higher than that of tap water. Moreover, it was also significantly higher than that of KCl and JHC at the same concentration. It could be concluded that the prepared polymer microsphere had excellent shale hydration and dispersion inhibition capacity.

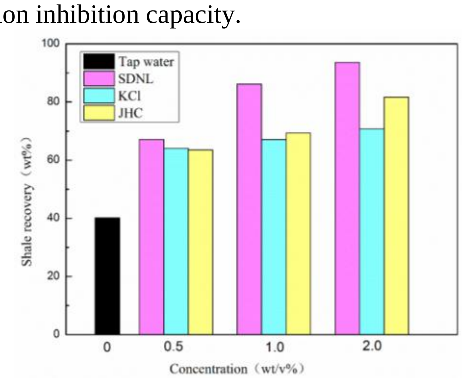

Fig. 4. The test results of shale recovery rate.

3.5 Linear swelling test

The linear swelling test was conducted to evaluate the inhibition performance of the prepared polymer microsphere. The lower swelling rate indicated the better shale inhibition performance. Inorganic salts (KCl) and polymeric alcohol (JHC) as two common used shale inhibitors were chosen to compare with the prepared polymer microsphere. In brief, the shale samples were crushed to less than 100 mesh. Then, they were oven-dried at 105 ℃ for 4 hours. Pressing 10g of crushed shale samples at 10MPa for 5 minutes to prepare a shale core. And the initial height of the shale core was recorded. The expansion instrument (NP-02A, Haitongda Company, China) was used to measure the swelling height of the shale core, after the testing fluid was contacted with the shale core. The swelling rate could be calculated through the measured swelling height of the shale core.

Fig. 5 shows the test results of linear swelling test. The swelling rate of shale samples in tap water was 12.5%, indicating that the hydration swelling capacity of the shale samples was strong. The shale hydration and swelling inhibition capacity of polymer microsphere was much better than frequently used shale inhibitors KCl and JHC. Under different concentrations, the swelling rate of polymer microsphere was lower than KCl and JHC. Eespecially, at the concentration of 2%, the swellling rate of polymer microsphere was only 4.9% and it was 2.55 times lower than that of tap water. Moreover, it was also significantly lower than that of KCl and JHC at the same concentration. It could be concluded that the prepared polymer microsphere had excellent shale hydration and swelling inhibition capacity.

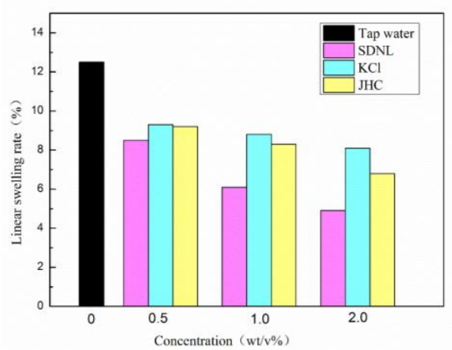

Fig. 5. The test results of linear swelling test.

On the basis of the above experiments, the excellent shale hydration inhibition mechanism of the polymer microsphere could be concluded. With small particle size, large specific surface area and high surface energy, the polymer microsphere could be easily adsorbed onto the shale surface. In addition, the hydrogen bonds between clay surface and the polymer microsphere could further enhance the adsorption ability. In addition, the hydrophobic isolation film could further prevent water molecules into clay particles clearance. Therefore, the prepared polymer microsphere could effectively inhibit shale hydration swelling and dispersion.

3.6 Pressure transmission test

The sealing performance for the prepared polymer microsphere was evaluated through the pressure transmission test, and the test was conducted on a simulation experiment device for pressure transmission [6]. The simulation experiment device was shown in Fig. 6. The experiment device was composed of five parts, including a high temperature-pressure kettle, a fluid circulation system, a hydraulic control system, a temperature transfer and control system, and a data acquisition-processing system. A shale sample was put into core holder, and the testing fluid was put into the upstream inlet. During the test, 2.0 MPa was set for the upstream pressure and it was maitained throughout the experiments. 1.0 MPa was set for the initial downstream pressure. Pressure transmission curves was recorded by the data acquisition-processing system. Through the pressure transmission curves, the sealing performace of the prepared polymer microsphere could be analyzed. In addition, the base fluid for the pressure transmission test was composed of 4.0% pre-hydrated sodium bentonite slurry.

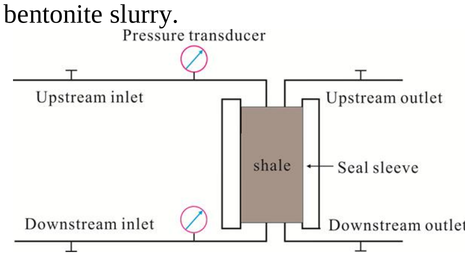

Fig. 6. The simulation experiment device for pressure transmission test.

The pressure transmission curves are shown in Fig. 7. It took 2400 s for the shale sample to reach a balance between the upstream and downstream pressure, and 7700 s for the base fluid. After interacting with the base fluid containing 2.0% polymer microsphere, it took 16300 s for the pore pressure to reach 1.8 MPa. Thus, the time for the base fluid containing 2.0% polymer microsphere to reach a balance was much longer than the shale sample and the base fluid. As shown in Fig. 7, it could be clearly seen that it was almost no longer increased after the pore pressure reached to 1.8 MPa. It indicated that a dense plugging film had formed on the shale surface, and the polymer microsphere could effectively retard pore pressure transmission. Therefore, the polymer microsphere possessed strong plugging capacity.

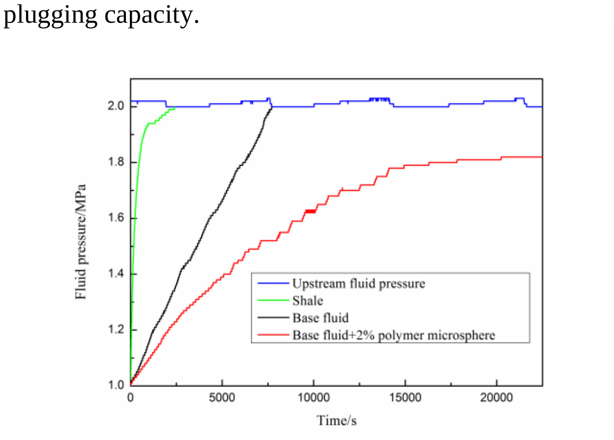

Fig. 7. The pressure transmission curves.

Fig. 8 presents the plugging mechanism of the prepared polymer microsphere. As shown in Fig. 8, under the drilling differential pressure the polymer microsphere relied on its elastic deformation and could seal the shale pore throats and cracks. After a period of time, a dense plugging film was gradually formed on the shale surface. The permeability of the shale surface was almost zero, and the transmission rate of the pore pressure was extremely low. Therefore, in the drilling process, the polymer microsphere could be used as an effient plugging agent as it possessed the capacity of retarding pore pressure transmission.

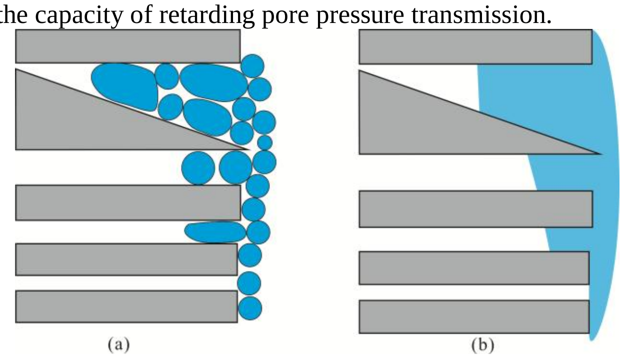

Fig. 8. Schematic diagram of plugging mechanism, (a) compression and deformation of polymer microspheres and (b) formation of a dense plugging film.

4 Conclusions

In summary, a novel polymer microsphere was successfully prepared by emulsion polymerization as a shale stabilizer for water-based drilling fluids. The hot-rolling cuttings dispersion test and linear swelling test indicated that the prepared polymer microsphere had good performance to prevent shale hydration. In addition, the pressure transmission test proved that the prepared polymer microsphere could effectively retard pore pressure transmission and reduce the permeability of shale samples. Hence, the prepared novel nano-sized polymer microsphere may be a potential stabilizer in the water-based drilling fluids for drilling troublesome shale formations.

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