Conformance Control through In-situ Gelation of Silica Nanoparticles

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ABSTRACT

The conformance control technique proposed in this paper uses colloidal silica (aqueous silica nanoparticle dispersions) for a gelling system to address conformance control in reservoirs with fractures or high permeability contrast layers. The goal is not to permanently plug but to reduce conductivity and promote more even flow. Porous media flow experiments were used to test the hypothesis that the gelled nanoparticle dispersions, triggered in-situ due to salinity contrasts, would be an effective conformance control process at the core scale. The gelation behavior was first looked at in matrix flow to gain an understanding of the impact of salinity gradient and nanoparticle concentration. Then the process was tested in an artificially fractured core. Permeability reduction was achieved even at low nanoparticle concentrations. Under retarded gelation kinetics, permeability reduction can be created deeper in the core. For the process in a fractured core, gelation generated a three-fold pressure increase.

Keywords: silica nanoparticles, conformance control, flow through permeable media, fractured reservoirs, high permeability contrast layers

1 INTRODUCTION

Due to reservoir heterogeneities, oil recovery from fluid injection during secondary and/or tertiary recovery does not occur in an ideal piston-like displacement. Rather sweep efficiency can be much lower than 100% due to heterogeneities such as high permeability contrast between layers (aka thief zones) and fractures. These reservoir features require the use of a conformance control agent to improve sweep. The conformance control technique proposed in this paper uses colloidal silica (aqueous silica nanoparticle dispersions) for a gelling system to address conformance control. The difference between this process and past work on colloidal silica[1-4] is that no activator is used prior to injection. Rather, the salinity of the formation water is used as an in-situ activator. This eliminates the need for a preflush to condition the reservoir. Previous work by the authors[5] explored the gelation properties of the silica nanoparticle dispersions in the presence of NaCl to determine their scope for in-situ conformance control. The target for this technology is fractured viscous oil reservoirs. The goal is not to permanently plug the fractures, but to reduce their conductivity and promote more even flow between the matrix and fractures.

Porous media flow experiments were used to test the hypothesis that the gelled nanoparticle dispersions, triggered in-situ due to salinity contrasts, would be an effective conformance control process at the core scale. The gelation behavior was first looked at in matrix flow to gain an understanding of the mixing behavior through four core floods studying the process controls – salinity gradient and nanoparticle concentration – and as preliminary work for injection in high contrast layers. Then a preliminary test was performed in an artificially fractured core.

2 MATERIALS AND METHODS

The material under study is aqueous dispersions of silica nanoparticles. The NexSil5 nanoparticles purchased from Nyacol have a bimodal size distribution with peaks at 3 and 18 nm. Saline solutions were made with solid NaCl from Fisher Scientific and distilled water (DI). All experiments were run using one foot long, 1.5 inch diameter Estallades limestone cores. Figure 1 is a schematic of the experimental set-up with 1: Isco LC-5000 syringe pump, 500 mL capacity; 2: stainless steel double-ended accumulator for brine solution; 3: stainless steel double-ended accumulator for nanoparticle dispersion; 4: Phoenix Instruments core holder – 1 ½" diameter, 1' length; and 5: Teledyne Isco Retriever 500 fraction accumulators with disposable 15 mL plastic centrifuge test tubes. Black dots are pressure measurement points. The absolute pressure is measured at the inlet (bottom dot), and differential pressures are measured over sections one, two, and three. Sections one and three are three inches long; section two is six inches long.

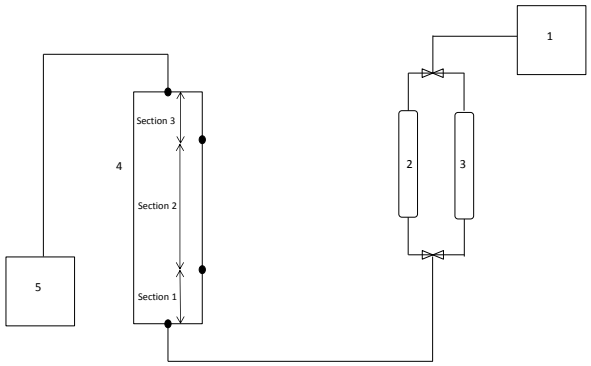

Figure 1: Schematic of conformance control core-flood set-up.

Each experiment had two steps – porosity and permeability measurement during initial core saturation and nanoparticle injection. Once the necessary measurements were completed, nanoparticle injection was started. The nanoparticle dispersion was injected for 24 to 36 hours with the effluent collected every hour. The injection rate was set so that the interstitial velocity was the same for all experiments. At the end of the experiment, the conductivity and absorbance of each sample was measured. The absorbance can be related to nanoparticle concentration through the calibration curve in Figure 2. The conductivity measurements were made with a conductivity probe. The absorbance measurements were done with a UV-Vis spectrometer. The absorbance was measured from 380 to 800 nm, but only the 400 nm measurements were reported.

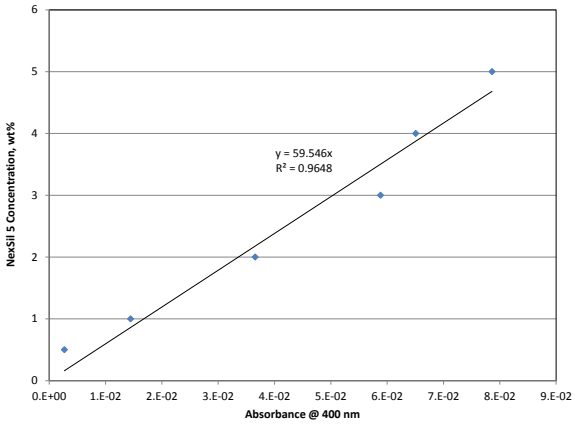

Figure 2: Calibration curve between absorbance and nanoparticle concentration.

3 RESULTS AND DISCUSSION

Three matrix experiments were designed to study the effect of salinity gradient and nanoparticle concentration on the in-situ gelattion process. The final experiment looked at the gel's performance in a fractured core, created by cutting the core in half lengthwise. The first gelation case was designed to serve as the reference case for comparison to the subsequent cases. Figure 3 shows the pressure drop during nanoparticle injection. A seven-fold increase in pressure is observed in section one. This means that for this nanoparticle concentration/salinity gradient combination, near wellbore application would be suitable as the gelation kinetics prevent deep gel placement. After the salinity front has progressed through the core, no further gelation should occur as the trigger mechanism (salinity gradient) has been removed. Gelation could be reinitiated if the nanoparticle injection was chased by high salinity brine.

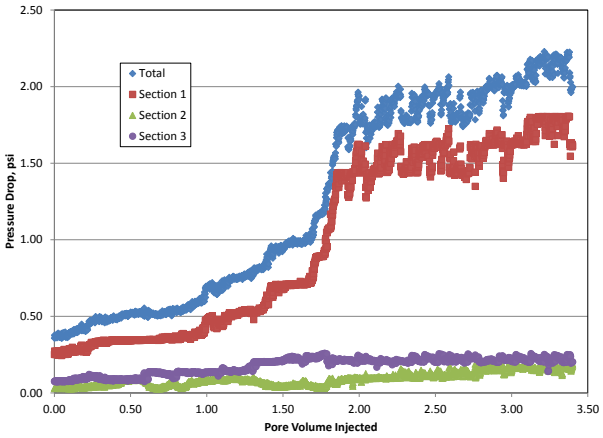

Figure 3: Pressure history during gelling nanoparticle injection for Reference Case.

The next experiment (Experiment 2) looks at the impact of nanoparticle concentration on the process by decreasing the concentration from 2 wt% to 1 wt%. Figure 4 shows the pressure drop histories during nanoparticle injection. A five-fold pressure increase in observed in section one. This suggests that while conductivity reduction can be achieved at lower nanoparticle concentrations, it is more significant at the higher concentration, but not proportionally so. The stair-step behavior in section one pressure for Experiment 2 suggests that the gelation progressively occurs in different portions of the core. Most likely, the largest pores are gelled first. When flow through these pores is impeded significantly, the nanoparticle solution is diverted to the smaller pores. The progression continues until the nanoparticles arrive at pores that are not saturated with high enough salinity to trigger gelation.

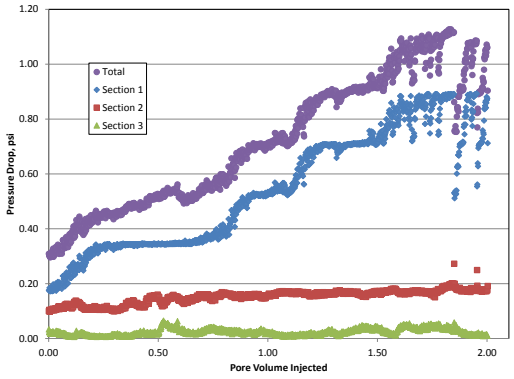

Figure 4: Pressure histories during gelling nanoparticle injection for Experiment 2.

The final matrix experiment (Experiment 3) looked at the impact of also decreasing the salinity gradient. From the previous work [5], gelation should be retarded at lower mixing salinities. For this case, the same nanoparticle solution was used as in Experiment 2 with an initial core salinity of 2.0 wt% NaCl. Figure 5 shows the pressure

drops during nanoparticle injection. Unlike the previous experiments, pressure increase is observed in section two (six-fold) as well as section one (eight-fold) indicating deeper placement of the gel. Even though the plugging is not as severe in section two, it would still be sufficient to divert flow and indicates the potential for deeper placement of the gel even when the gelation occurs near the inlet (section one). In addition to having the longest gelation time, Experiment 3 also displays loss of blockage as the pressure in section 1 drops down at 2.3 PV. This behavior supports the assertion that the gel can be partially broken upon continued injection. Because this failure was not observed in Experiment 2, the results suggest that at lower initial core salinity, the gel formed is more susceptible to failure. This is supported by the dynamic shear tests from the previous work [5] that show increasing G' (storage modulus) for the gels as NaCl concentration increases.

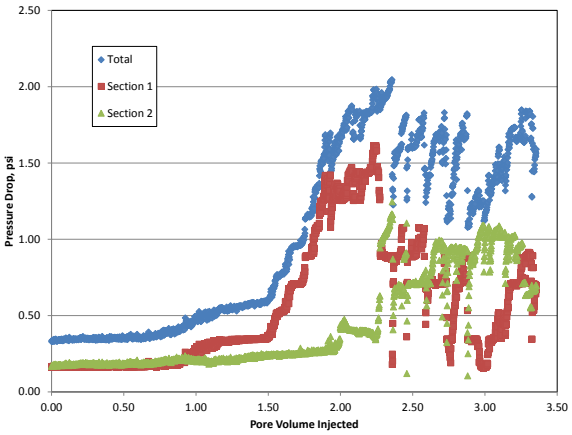

Figure 5: Pressure drop during gelling nanoparticle injection for Experiment 3.

The final experiment (Fracture Case) looks at the gel's performance in a fractured core. The same initial and injection conditions were used as in the Reference Case. Overall, a 3-fold pressure increase is observed, which is the smallest conductivity decrease of all the experiments (see Figure 6). As flow is fracture-dominated, any observed pressure increase occurs in the fracture. It is likely, due to the morphology of the artifical fracture, that the gel is displaced under continued injection. However, when the initial gel causes the fracture pressure to build up, the injected nanoparticle solution enters the matrix displacing the orignal high salinity brine back into the fracture. This allows for the formation of a transient gel upon mixing of the displaced brine and nanoparticle disperison that enters the matrix after the original gel is flushed.

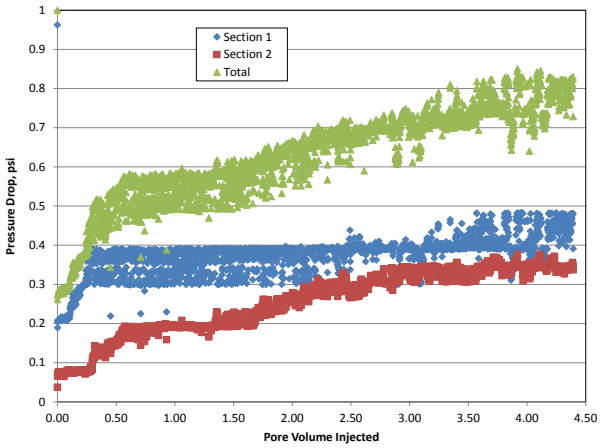

Figure 6: Pressure drop during gelling nanoparticle injection for the Fracture Case.

4 CONCLUSIONS

Four matrix injection experiments were run to study the potential of nanoparticle gelation triggered in-situ by salinity gradients. The results show that permeability reduction can be achieved through the process even at low concentrations of nanoparticle. For faster-gelling systems (Reference Case and Experiment 2), permeability reduction only occurs in section one. However, under retarded gelation kinetics due to lower initial salinity (Experiment 3), permeability reduction is significantly extended away from the injeciton point. . When the core salinity is initially lower, a weaker gel is formed, which allows for continued injection to break and mobilize some of the gel. The gelation process was also explored in a fractured core. At the experimental conditions, gelation generated a three-fold pressure increase. The nature of the artificial fracture core results in displacement of the intial gelation but subsequent formation of transient gels as high salinity brine displaced from the matrix mixes with fresh nanoparticle solution being injected.

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