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Evaluation of Nanoparticle Application to Control Formation Damage in Porous Media: Laboratory and Mathematical Modelling

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Abstract : Suspension-Colloidal flow in porous media occurs in numerous engineering fields, such as industrial water treatment, the disposal of industrial wastes into aquifers with the propagation of contaminants and low salinity water injection into petroleum reservoirs. The main effects are particle mobilization and captured by the porous rock, which can cause pore plugging and permeability reduction which is known as formation damage. Various factors such as fluid salinity, pH, temperature, and rock properties affect particle detachment. Formation damage is unfavorable specifically near injection and production wells. One way to control formation damage is pre-treatment of the rock with nanoparticles. Adsorption of nanoparticles on fines and rock surfaces alters zeta-potential of the surfaces and enhances the attachment force between the rock and fine particles. The main objective of this study is to develop a two-stage mathematical model for (1) flow and adsorption of nanoparticles on the rock in the pre-treatment stage and (2) fines migration and permeability reduction during the water production after the pre-treatment. The model accounts for adsorption and desorption of nanoparticles, fines migration, and kinetics of particle capture. The system of equations allows for the exact solution. The non-self-similar wave-interaction problem was solved by the Method of Characteristics. The analytical model is new in two ways: First, it accounts for the specific boundary and initial condition describing the injection of nanoparticle and production from the pre-treated porous media; second, it contains the effect of nanoparticle sorption hysteresis. The derived analytical model contains explicit formulae for the concentration fronts along with pressure drop. The solution is used to determine the optimal injection concentration of nanoparticle to avoid formation damage. The mathematical model was validated via an innovative laboratory program. The laboratory study includes two sets of core-flood experiments: (1) production of water without nanoparticle pre-treatment; (2) pre-treatment of a similar core with nanoparticles followed by water production. Positively-charged Alumina nanoparticles with the average particle size of 100 nm were used for the rock pre-treatment. The core was saturated with the nanoparticles and then flushed with low salinity water; pressure drop across the core and the outlet fine concentration was monitored and used for model validation. The results of the analytical modeling showed a significant reduction in the fine outlet concentration and formation damage. This observation was in great agreement with the results of core-flood data. The exact solution accurately describes fines particle breakthroughs and evaluates the positive effect of nanoparticles in formation damage. We show that the adsorbed concentration of nanoparticle highly affects the permeability of the porous media. For the laboratory case presented, the reduction of permeability after 1 PVI production in the pre-treated scenario is 50% lower than the reference case. The main outcome of this study is to provide a validated mathematical model to evaluate the effect of nanoparticles on formation damage.

Keywords : nano-particles, formation damage, permeability, fines migration
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