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High-Resolution Monitoring of Nanoparticle Transport Behavior in Multi-Phase Saturated Porous Media: Experimental Study

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Nanoparticles are emerging as an important advancement in the petroleum industry, including in enhanced oil recovery. Nanoparticles have shown potential to mitigate some of the issues associated with enhanced oil recovery due to their impact on bulk and interfacial properties. However, before their application in any EOR operation, the study of nanoparticle transport behavior in porous media is of prime importance. The reservoir condition such as high temperature, high pressure, the presence of multi-phase fluids, and salinity can significantly affect the nanoparticle transport behavior, which is the focus of this study.

In order to understand the behavior of nanoparticles in porous media, a series of single-phase and multi-phase nanofluid floods were performed through unconsolidated sandpacks under reservoir conditions. Using a highly specialized core flooding apparatus with the capacity to handle high temperature (150 °C) and high pressure (35 MPa), nanofluid slugs were injected into the porous media followed by a post-flush of brine. An inert chemical tracer was used to characterize the dispersivity of the porous media. Experimental variables included the type of nanoparticle, concentration, salinity, temperature (up to 120 °C), pressure (up to 5 Mpa), flow rate, and effect of oil (Dodecane). Propagation was observed through the sandpack using four differential pressure transducers located along the length of the pack. Measurements of permeability were taken before and after the nanofluid slug at varying flow rates in order to determine the effect of the nanoparticle on permeability. High-resolution analysis of the concentration of nanoparticles in the influent and effluent from analysis by Triple Quadrupole ICP-MS provided the breakthrough curve, as well as the adsorption and retention of the nanoparticles in the sandpack.

The result of this study indicated that the factors affecting nanoparticle transport and retention the most were nanoparticle type, salinity, and the presence of oil phase. The pressure (up to 5 Mpa) and temperature (120 °C) were shown to have an insignificant effect on the behavior of the studied nanoparticles in the porous media. According to the particle size measurement and ICPMS results, the retention of uncoated silica nanoparticles was the same in the presence of oil compared to that of single-phase retention where recovery of nanoparticle was more than 80%. The increase in the post-flush flow rate (10 times) did not increase the nanoparticle recovery. While increasing the salinity was shown to reduce fines migration, it reduced the stability of the nanoparticles and caused aggregation, resulting in increased retention and permeability reduction. However, some of the studied nanoparticles showed good salt tolerance at reservoir condition. In addition, the studied silica nanoparticle had minimal permeability reduction, making them a viable option for additives in EOR. Furthermore, the results of multiphase flow experiments showed that the presence of fines in the porous media, and their combination with nanofluid resulted in emulsion generation and oil recovery up to 70% while the nanofluid and oil phase did not make any emulsion in bulk tests study.

The results of this study broaden our understanding of how nanoparticles interact in porous media under reservoir conditions. Once the mechanisms of nanoparticle transport and retention are better understood in single-phase and multi-phase transport, they can be studied in a wide range of applications including polymer flooding, surfactant additives, and steam-foam stabilization. Nanoparticles have the potential to improve enhanced oil recovery by reducing chemical additives and water required, making existing methods more effective, and reducing the environmental impact of oil recovery processes.

References

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