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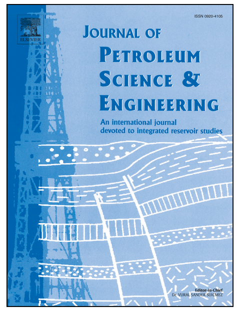

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Successful Crosswell Field Test of Fluorescent Carbogenic Nanoparticles

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Abstract

This manuscript reports the industry's first proven reservoir nanoagents' design and describes a successful crosswell field trial using these inexpensive and environmentally friendly nanoparticles that offer an important advantage of fast and cheap fluorometric detection. Our fundamental nanoparticle tracer template, A-Dots, is intentionally geared towards the harsh but prolific carbonate reservoir environment of 100°C temperature, 150,000 ppm salinity, and an abundant presence of divalent ions in the connate water. The A-Dots were manufactured on a scale of one metric ton from affordable and easily available commodity chemicals. They were injected into a watered-out part of the field and monitored at four nearby producer wells for two years. Monitoring of four neighboring producer wells over a period of 26 months confirmed nanoparticles' breakthrough at a single producer nearly 500 m from the injector at the reservoir level, thus, proving the nanoparticles' mobility and transport capability. The maximum concentration of the nanoagent in produced water was observed about 10 months after the injection matching the behavior of conventional small-molecule tracers used in the same pai4 of wells previously.

This test supported our previous observations of satisfactory recovery of A-Dots in a single-well test by confirming their reservoir stability on industry relevant time scales and demonstrating the feasibility of their industrial production. The importance of this accomplishment is not in how sophisticated the sensing functionality of the tracer design is but rather in the nanoparticle stability, mobility, scalability, and field application potentials. Our findings render the concept of having active, reactive, and even communicative, in-situ reservoir nanoagents for underground sensing and intervention a well anticipated near-future reality.

Introduction

Nanotechnology has provided various creative solutions to the daily problems of hydrocarbon exploration and production that are being implemented in commercial products. Better understanding of physical and chemical phenomena governing the behavior of particles on 1-100 nanometer scale gave rise to superhydrophilic (Faustini et al, 2015; Ji et al., 2015; Rodrigues et al., 2016) and superhydrophobic (Chen et al., 2015; Gao and Jia, 2015; Gao et al., 2016; Wu et al., 2016) coatings, shale-inhibitive water-based drilling fluids (Young et al., 2013), near-wellbore fines control agents (Abad et al., 2013) and soluble metal alloys for use in hydraulic fracturing (Li and Ma, 2014). In addition to imparting unique properties of bulk materials, engineered nanoparticles hold a great promise for hydrocarbon exploration and production as individual entities acting as reservoir-traversing agents capable of changing or monitoring of reservoir conditions. A few of nanoparticle applications, such as surfactant nanoparticles (Abdel-Fattah et al., 2017), oil-sensing nanoparticles, superparamagnetic nanoparticles for electromagnetic imaging contrast enhancement (Al-shehri at al., 2013) and nanoparticle tracers are presently in fairly advanced stages of laboratory development. Evidently, the utility of any nanoparticle-based reservoir agent is determined by its capacity to survive the inhospitable conditions of hydrocarbon bearing formations for the entire duration of its mission. The most challenging of them are the high salinity and hardness of connate brines, high temperature and the presence of a very expansive and chemically diverse rock surface. Even before any advanced functionality incorporation into a nanoagent can be considered, fully compatible answers to all of these challenges must be at hand. Application of suitable polymer coatings to nanoparticles that were by themselves unstable in connate brines provided them with noticeably improved stability to flocculation and adsorption. Unfortunately, the stability improvements allowed the coated particles to travel through only impractically short sand columns or small plugs of reservoir rock. A welcome breakthrough in the