Enhancing oil recovery using nanoparticles

A PhD studentship to be run by the Petrophysics Research Group in the School of Earth and Environment at the University of Leeds

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Summary

- An opportunity to combine experimental work, physical modelling and numerical modelling in a single research project.
- The project contains pure research as well as major aspects of direct applicability to industry.
- Join a diverse research group covering all aspects of rock physics with an international reputation and links to industry.
- Attend international conferences in the Europe, the US and elsewhere.
- The project is supported by successful pilot studies with the potential to generate early publications and consequent option of PhD assessment by publications alone.
- Tutoring in career development (academia, industry and beyond).

Motivation. As the world moves into the third decade of the 21st century, developed and developing nations still depend critically upon materials derived from oil. However, the Earth's natural oil resources have been significantly depleted. Most existing large and simple reservoirs have reached or are reaching the end of their practical production lifetimes with over 40% of their original oil still in place, yet not producible. Smaller and more complex reservoirs can fill the production gap, but are expensive and run the risk of damaging the environment. It would be far better to find ways of extracting more oil from the reservoirs that we currently have.

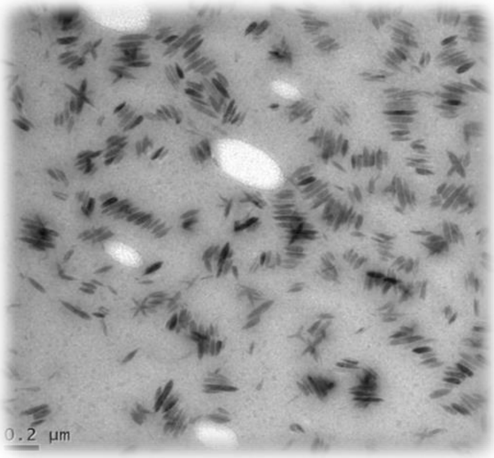
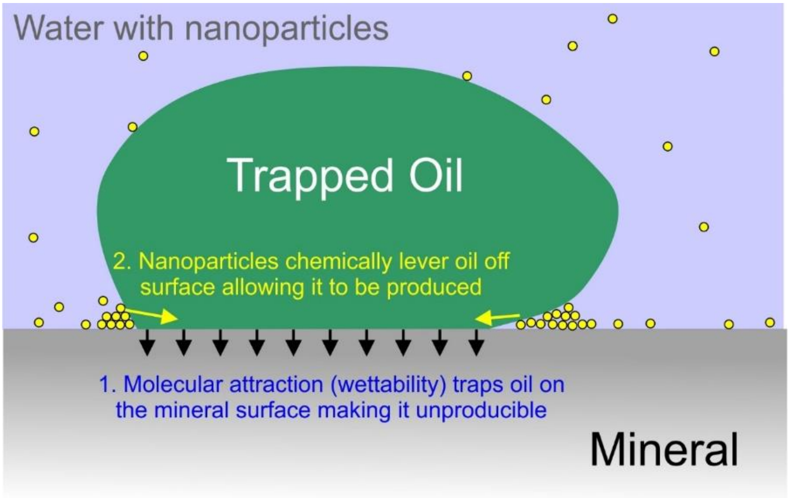


Fig. 1. Transmission electron microscope image of rutile TiO_2 nanoparticles (Hu et al., 2016)

A pilot study at the University of Leeds has shown that the injection of nanoparticles suspended in aqueous fluids can result in 33% more oil being produced (Hu et al., 2016). A wide range of different nanoparticles, including rod-like rutile (Fig. 1) and grain-like anatase TiO_2 crystals, as well as microscopic quartz crystals and even the nanoscale carbon quantum dots (CQDs) (Hu et al., submitted) are available for us to study. Several mechanisms for the improvement in recovery factor have been proposed. In the first (see image below) the surface properties of the nanoparticles attract them to the mineral surfaces and effectively lever oil which is attached to those surfaces off (Fig. 2). This is a form of wettability modification, making the mineral services more water wet and hence mobilising oil droplets so they can be produced. A second mechanism involves waterborne nanoparticles blocking high permeability pathways which carry water past other pathways that contain trapped oil. The result is that the water must now take the low permeability pathway containing the trapped oil, and in doing so mobilises it for production. The study of these processes will be one of the goals of the doctoral research.



◀ *Fig. 2. One of the proposed micro-mechanisms for explaining how nanoparticle enhanced oil recovery (nEOR) works (nanoparticle diameter about 50 nm).*

Aims and Objectives. The aim of the research is to understand the effect of nanoparticles on improvements to oil production from reservoirs using experimental measurements, imaging and associated analogue and numerical modelling. Its objectives include:

- Measuring oil production enhancement using nanoparticle-rich water-flooding on a range of reservoir rocks in the laboratory.
- Assessing which types and sizes of nanoparticles produce the best production enhancement, and how these particles can be stabilised during nanoparticle flooding.
- Development of an understanding of the proposed 'wettability-modification' and 'log jamming' mechanisms for hydrocarbon enhancement.
- Examination of the microscopic effects of nanoparticle infiltration in reservoir rocks using physical modelling and imaging.
- Calculation of the impact of using nanoparticle water-flooding on a range of candidate reservoirs using numerical modelling.
- Calculation of the impact of nanoparticle water-flooding on all reservoirs worldwide which might potentially benefit from the application of this technology using socio-economic modelling.

Methodology. The PhD will progress in four overlapping strands.

- The first strand is experimental and will involve carrying out a number of laboratory-based measurements of oil recovery from reservoir rocks of different types using different types (rutile an anatase), sizes and concentrations of nanoparticles suspended in water with different concentrations of surfactant stabiliser. These experiments will ascertain the optimum parameters for carrying out nanoparticle flooding in large-scale reservoirs, i.e. those parameters required to extract the maximum amount of hydrocarbons.

- The second strand involves physical modelling of nanoparticles passing through the rock microstructure in an experimental cell that will allow the process to be imaged. This experimentation and imaging will be combined with the other experimental work to study microscale processes which lead to increased production such as wettability-modification and log-jamming.
- The third strand will involve numerical reservoir modelling (Fig.3) using state-of-the-art software available at the University of Leeds and the expertise within the Advanced Fractal Reservoir Modelling section of the Petrophysics Group (Al-Zainaldin, 2017; Glover et al., 2018). This software will be used to model the production of oil with time for a number of well-characterised reservoirs which have well-known production data. This modelling is necessary to evaluate the impact of increased oil production observed at the experimental scale when it is applied to the full reservoir scale.
- A fourth and final strand to the PhD involves a limited amount of socio-economic modelling. This simple modelling allows will assess the likely impact of nanofluid implementation in all fields that might benefit from it in order to produce an effective maximum benefit from rolling the method out globally.

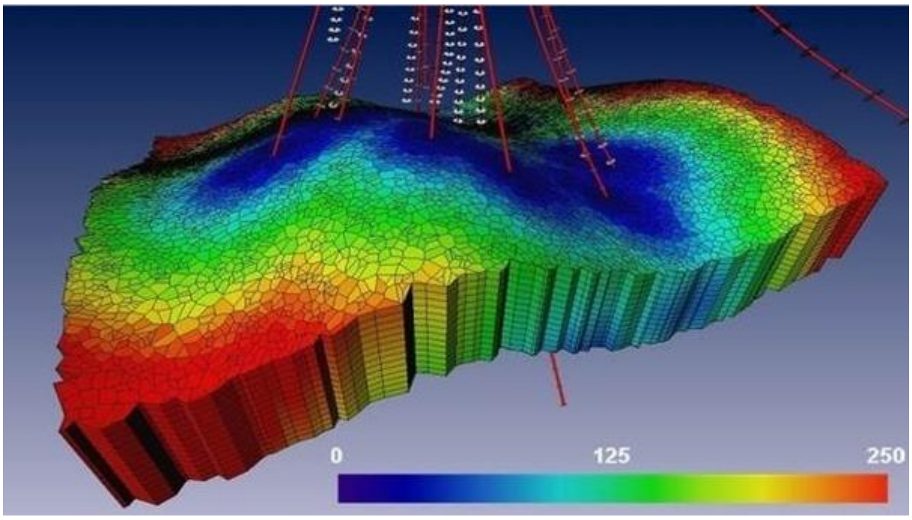


Fig. 3. A typical reservoir model which allows the production of oil from a reservoir to be calculated during production and compared with the actual production so that the impact of processes such as nanoflooding can be assessed (Horizontal and vertical extents are 2.5 km and 20 m, respectively. The scale bar is oil pressure relative to well pressure in MPa, Open Source).

Scope. This PhD proposal is unusual in that it combines experimental measurements, physical modelling, imaging, numerical reservoir modelling and socio-economic modelling in one piece of work, making it a potentially very interesting piece of research. The experimental work is prefigured by a successful pilot study which has already led to one scientific paper (Hu et al., 2016) and another submitted (Hu et al., submitted). The experimental, physical modelling and imaging work will be carried out in the petrophysical laboratory of the School of Earth and Environment with supporting experiments in the School of Chemical and Process Engineering. Numerical reservoir modelling and socio-economic modelling will be carried out in the School of Earth and Environment using state-of-the-art software. The supervisory team is extremely experienced in petroleum engineering, petrophysics and reservoir modelling, and has an excellent track record in PhD supervision. All relevant health, safety and technology-specific training will be provided. It is expected that the student will present scientific papers at conferences in at least two years of the PhD, and will submit multiple scientific papers to journals before the PhD finishes.

Eligibility. Applicants should have a BSc/BEng degree (or equivalent) in geology, earth sciences, geophysics, petroleum engineering, chemistry, chemical engineering, physics or a similar discipline. An MSc, MGeol or MEng in one of the aforementioned disciplines would be an advantage. Skills in experimental design, fluid flow experiments, FEM and/or reservoir modelling are desirable. A reasonable competence in mathematics is expected. An ability to code would be useful, though not essential.

Training. The successful applicant will work within the inter-disciplinary Petrophysics Research Group, which is part of the wider Institute of Applied Geosciences at the School of Earth and Environment, University of Leeds. The Petrophysics Research Group has graduated 13 PhD students since 2012, and has 5 on-going research sections related to (i) tight carbonate petrophysics, (ii) advanced fractal reservoir simulation, (iii) gas shale research, (iv) reservoir nanoflooding, and (v) the electrical and electro-kinetic properties of rocks. The project will provide specialist scientific training, as appropriate, in: (i) laboratory procedures for preparing nanofluids and carrying out experimental water-flooding; (ii) physical modelling and image analysis; (iii) statistical analysis; (iv) FEM and reservoir modelling. The mixed pure- and applied-science nature of this research project will enable the student to consider a future career in either academia or industry. In addition, the student will have access to a broad spectrum of training workshops provided by the Faculty that include an extensive range of training workshops in statistics, through to managing your degree, to preparing for your viva (http://www.emeskillstraining.leeds.ac.uk). The successful candidate will be strongly encouraged and supported to publish the outcomes of their research in leading international journals.

References and bibliography

AL-ZAINALDIN, S., GLOVER, P.W.J. and LORINCZI, P., 2017. Synthetic Fractal Modelling of Heterogeneous and Anisotropic Reservoirs for Use in Simulation Studies: Implications on Their Hydrocarbon Recovery Prediction. Transport in Porous Media, 116(1), pp. 181-212.

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HU, Z., AZMI, S.M., RAZA, G., GLOVER, P.W.J. and WEN, D., 2016. Nanoparticle-Assisted Water-Flooding in Berea Sandstones. Energy and Fuels, 30(4), pp. 2791-2804.

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Further Information

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