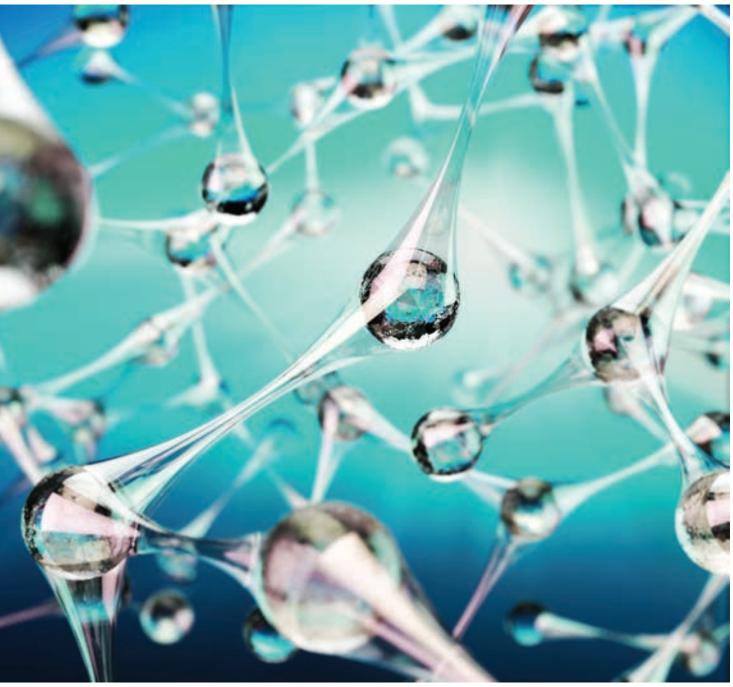
NANOTECHNOLOGY

A potential game-changer



Application of nanotechnology in the oil and gas sector is considered by some researchers to be a game-changing technology, particularly for drilling engineering and enhanced oil recovery. *Brian Davis* reports.

Nanotechnology and nanostructure with nanoparticles, atomic and molecular structure, chemical bonds and science concept, crystal lattice network model
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According to leading oil industry researchers nanotechnology could benefit numerous areas in the oil and gas sector. Applications are being tested with promising results using nanoparticles in drilling fluids to reduce torque and drag, stabilising the well bore, controlling fluid loss and improving down-hole cleaning efficiency.

Using specialist techniques to synthesise nanoparticles at atomic level, these particles have been shown to have remarkable mechanical, optical and magnetic properties, which have potential applications both upstream and downstream.

Upstream benefits include improving the rheological and filtration properties of drilling fluids, the quality of mud cake, decreasing frictional resistance in the well, minimising the risk of pipe sticking, improving borehole stability, preventing formation damage in the reservoir, and enhancing oil and gas recovery (EOR). Most of these applications are still in the research and development stage. Oxides of zinc, aluminium, iron, magnesium, nickel, zirconium, silicon and tin are being studied for EOR.

However, downstream, nanoparticles have been applied for some time – especially as catalysts, as they can be used to extract sulphur dioxide (SO_2), nitrogen oxides (NO_x) and acids from vapour. Nano-membranes can also be used to separate the gas stream and remove impurities from oil. In addition, nano-catalysts are being used to upgrade heavy oil and bitumen.

The dimension of a nanoparticle is generally between 1 and 100 nanometres (nm) in size. The physical and chemical properties of nanoparticles may differ from bulk materials in terms of surface area effects, aggregation, melting point, optical properties, magnetic properties, solubility and mechanical strength, to mention just a few.

Different fields like medicine, electronics and developers of composite materials have been faster to exploit nanoparticles commercially than the energy industry, which tends to be more conservative. But some oil majors are cautiously investigating the potential of nanotechnology for exploration, drilling, reservoir protection, hydrocarbon recovery and processing.

The main concerns are the high cost of nanoparticles, lack of sufficient pilot projects, field tests, and safety. Nanoparticles pose a significant health and safety risk which requires special handling under controlled conditions as the tiny particles are carcinogenic, very light and easily disseminated.

Growing interest

There is growing interest from the exploration, drilling, production, processing and refining sectors. Nanoparticles for these applications are being developed in the US, China and companies like Wintershall in Germany. Notably, nano-sensors have been developed for subsurface imaging. Meanwhile, research into the use of nanotechnology for EOR is underway at Aberdeen University under the leadership of Dr Roozbeh Rafati, Lecturer in Petroleum Engineering.

'Nanotechnology is being used for viscosity enhancement and as a form of stabiliser in reservoirs,' he explains. 'For example, nanoparticles can be injected in a foam with water-soluble polymers as a viscosifier to improve gas and water mobility of formations. The nanomaterials can also strengthen the polymers and extend their effective life.'

Generally, the nanomaterials aggregate and block the formation. Rafati proposes the use of nanomaterials for heavy oil recovery for conventional reservoirs rather than EOR, because heavy oil reservoirs tend to be shallow and porosity is high, so the nanoparticles have a lower chance to block the pores in the reservoir. 'In the current downturn nobody is willing to test nanomaterials on normal reservoirs. The main opportunity will be for use on dead and abandoned reservoirs,' he says.

Nanomaterials tend to aggregate and form a sediment which is heavier than water sometimes, so they have to be agitated continuously or combined with viscosifiers like polymer for injection into the reservoir. This is particularly useful for a reservoir with a large amount of fractures, because the fractures are micro-sized and cannot be easily filled by cement.

Deep wells are particularly hostile environments in terms of high pressure and high temperature (HP/HT). Nano-sensors could be used under these severe conditions to recognise fluid types, for monitoring fluid flow and characterisation of the reservoir. Nano-chip tomography could also be used to image these formations.

Rafati is also investigating the potential application of nanoparticles in Arctic conditions, as well as the use for well plugging and abandonment during decommissioning. 'In the latter case, nanomaterials could be used to safely plug the wells. Alternatively, they could be injected with water as late-activated chemicals, which initially improve viscosity, then dissolve in water or oil when the

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temperature or pressure reaches a certain level,' he says.

Nanoparticles are generally less than 10 nm in diameter and can easily penetrate the pores in reservoirs, which measure 100 nm on average. But nanomaterials aggregate and when they reach a critical concentration will block the formation. Rafati compares the problem to having a factory in the desert with a filtered ventilation system, which gradually gets blocked with sand in time. So the filter has to be changed regularly.

For this reason, nanomaterials may be designed to self-destroy when the temperature or pressure reaches a certain level, or pH changes in the reservoir. This is a key area of research.

Drilling and completion

'Use of nanoparticles in drilling fluids enables the engineers to maintain wellbore stability and control fluid loss, especially in shale formation where the permeability is in nanodarcy (nD),' explains Dr Zhixin Yu, Professor of Petroleum Engineering at the University of Stavanger, in a recent co-authored paper.[1] Nano-based drilling fluid can also reduce torque and drag in extended reach and multilateral wells as it forms an ultrafine film between the pipe and hole wall, as well as eliminating bit and stabiliser balling.

Some nanoparticles, such as zinc oxide, in drilling fluids can be used as 'scavengers' to remove hydrogen sulphide (H_2S) from water-based mud before it reaches the surface. So the nanoparticles can help reduce pollution and prevent corrosion.

In HP/HT drilling operations (and low pressure/low temperature Arctic condition tests, mentions Rafati), nano-based drilling fluids offer high surface area and large thermal conductivity. These fluids can also reduce wear and tear of down-hole tools.

Nano-diamonds could also offer high mechanical strength in hostile environments down-hole. Spacers with nano-emulsions are also being tested in cementing operations. Nanoparticles, such as nanosilica (the most popular form of nanoparticle today), nano-alumina and carbon nanotube are under research worldwide to improve the performance of cement with respect to the hydration process, fluid loss, gas migration and compressive strength.

From an environmental perspective, nano-based drilling fluids utilise far less materials than conventional drilling fluids. However, Rafati points out that they could be hazardous if used in large volumes and require careful training and handling as they penetrate the skin and hair easily with carcinogenic effect.

Improved production

During the production phase, nanotechnology is under research for hydrate recovery, scale inhibition and stimulation fluid. Yu points out that hydrate recovery can be improved by injecting nickel-iron (Ni-Fe) nanoparticles into hydrate formations. Commonly a high molecular weight cross-linked polymer-based fluid is used. Research is also underway with low molecular weight surfactants as a fracture fluid with a nanoparticle for more efficient stimulation. Scale deposition on tubing can also be reduced using nanoparticles.

Addition of nanoparticles to drilling fluid in small concentrations can have marked effects. According to Yu, 0.57–1.71% graphene oxide in water-based drilling fluid can improve rheology, reduce fluid loss after heat ageing, and transport stabilisers in shale. Nanosilica (1–3% in water-based drilling mud) has excellent rheology and stabilises the wellbore by plugging pores in shale operations, as well as reducing filtrate loss. Iron oxide (0.1–0.4%) offers a higher yield point and more viscous behavior, with higher thermal stability. Addition of 2% carbon black to drilling fluid offers continuous and integrated mud cake formation.

Nanoparticles with graphite in oil-based mud can provide wellbore strengthening. Calcium-based nanoparticles have been shown to improve fracture resistance by 65%, whereas iron-based nanoparticles increased it by 39%. Mud filtration has also been studied in ceramic plate under HP/HT conditions to test wellbore strengthening using nanoparticles.

Key advantages of nanoparticles

Researchers claim there could be significant advantages using nano-drilling fluid compared to conventional drilling fluid.

- *Reduction in formation damage.* Nanoparticles protect the porosity/permeability characteristics of the near-well bore reservoir section and increases productivity.
- *Increase in shale stability.* The interaction between shale and mud can be minimised using nano-fluid.
- *Strengthening of unconsolidated formation.* Conventional particles are unable to combine and cement in macro- or micro-sized components, whereas nanoparticles can access pores and aggregate unconsolidated sands to increase fracture pressure and strengthen the well bore.
- *Formation of ultrafine mud cake.* Conventional drilling mud can form thick filter cake. Nano-based fluids form well-dispersed, thin and tight mud cake, reducing stuck pipe problems, minimising torque and drag and decreasing cuttings bed formation in deviated, horizontal and extended reach wells.
- *Improved drilling efficiency.* Nanoparticles improve drilling efficiency in HP/HT conditions, where temperatures and pressures exceed 150°C and 690 bar. Conventional chemical and polymer-based drilling fluids have limited thermal stability. Nanoparticles are stable under extreme conditions, and offer better viscosity and gelling properties at HP/HT, with excellent thermal conductivity, and good performance at very low temperatures. In addition, nanoparticle drilling mud improves torque and drag in horizontal and extended reach wells, while nano-drilling fluid helps avoid stuck pipe. Furthermore, nano-based drilling fluid can form a hydrophobic film as a barrier to bit balling, while nano-based drilling fluid can be customised to scavenge CO_2 and H_2S for more environmentally friendly operations.

'The biggest barriers to the use of nano-materials are the cost and lack of field tests,' admits Rafati. However, small concentrations can yield extraordinary results in terms of performance, as their high surface area makes them highly reactive. 'Nanotechnology is a potential future game-changer for the oil industry,' he says, 'but its application depends on the oil price, economical manufacturing and safety related issues.'

Indeed very 'small' could be 'beautiful' in the future oil and gas industry. ●

Reference

1 'The potential of nanotechnology in the petroleum industry', Irfran Y, Sui D, Agista MN and Zhixin Yu, Department of Petroleum Engineering, University of Stavanger, Norway.