Developing new technology is not an end unto itself – following through to implement it at scale and deliver benefits to commercial operations is where the payoff lies. In this roundup, *Terry Knott* looks at three successful BP technology developments which are now achieving positive results

Imagine an oil company claiming it had a magic potion that would help recover more oil from its reservoirs – at best this would most likely be met with a rather cautious response. But in its oil fields in Alaska and other parts of the world, BP is already applying just such a breakthrough chemical to good effect, helping the company produce many additional tens of thousands of barrels of oil.

The technique of waterflooding as a means to sweep more oil out of reservoir rock pores towards producing wells has been in use for decades. But it has its limits in terms of how much additional oil it can deliver, usually determined either by the nature of the reservoir geology or the economics of pumping large volumes of water at high pressure deep into reservoir formations.

Reservoir rock tends to be heterogeneous, having non-uniform characteristics which can cause unexpected results when water is pumped through it from injection wells. One such effect is that the injected water can flow fast through thin, highly permeable rock layers, in so doing bypassing much of the oil in the reservoir. The water that passes through these so-called 'thief zones' tends to break through to the production wells, and as the resulting hydrostatic pressure builds in the wells, the flow into them from the reservoir can slow down or even stop. While the industry has come up with a number of methods to try to block off the thief zones, such as physical barriers in or near the injection wells, these have proved only partially successful.

What was really needed was a 'smart' solution that would trigger itself automatically when it encountered a thief zone inside the reservoir, diverting the water to the oil-bearing zones of the formation. And a decade ago, inspired by an idea from the company's petroleum engineers, that is precisely what BP began working on in the Prudhoe Bay oil field in Alaska.

The net result of the development work, undertaken by BP in conjunction with Chevron and chemical company Nalco, was Bright Water, a technique and name now trademarked by Nalco (*Frontiers*, December 2007). Bright Water is a chemical treatment based on a long-chain, temperature-sensitive polymer, formulated as sub-micron particles suspended in a light mineral oil. The mixture is pumped into the reservoir along with the relatively cool injection water (see panel below). When this encounters the warmer thief zones – warmer because they are bounded by unswept warmer oil layers above and below – the sub-micron particles expand like popcorn to block the rock pores of the thief zones. The injection water is then diverted to the adjacent oil layers to drive the oil out of the reservoir – even a seemingly small percentage increase in recovery can amount to tens of thousands of additional barrels of oil.

'The beauty of Bright Water is that it activates itself where needed without us having to know the reservoir geology in detail,' says Paul Denyer, BP deployment manager for the technology. 'The polymer can be tailored to the application – to "pop" at a specific temperature. Injection is only needed for a few days or weeks without requiring additional capital equipment, and the results may start to come through as soon as three to six months later.'

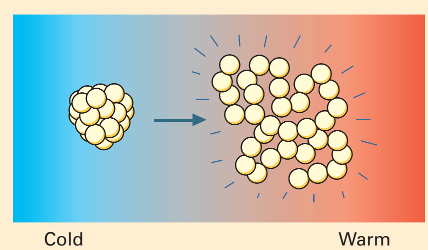
The technology is now available to the wider industry but BP leads the way in implementing Bright Water treatments, having pumped 26 so far. The majority of these have been in Alaska, where Bright Water has been applied to 17 wells in the BP-operated Prudhoe Bay, Aurora, Borealis, Milne Point and Niakuk fields, as well as to three wells in the ConocoPhillips-operated Kuparuk field, in which BP holds a 40 per cent stake. The treatments were undertaken after a successful 2004 trial in the Milne Point field, where Bright Water ›

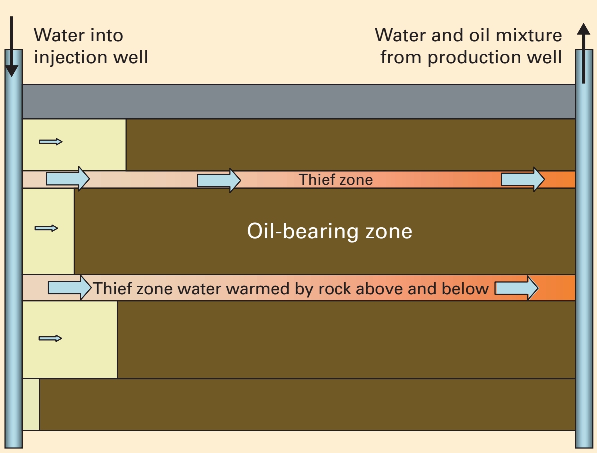
HOW BRIGHT WATER WORKS – 'THE POPCORN EFFECT'

Water injection can help drive oil from a reservoir, but this can also lead to problems. Thief zones of high permeability can take most of the water, causing it to be swept out of the reservoir rapidly, leading to early water breakthrough at the production well (diagram below left). There is then less driving force pushing the majority of the oil out.

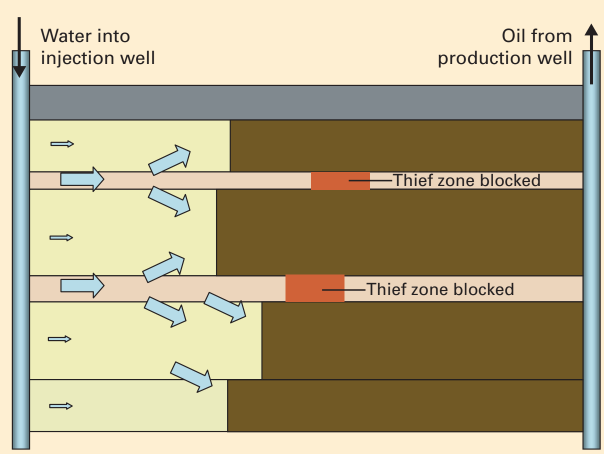
Bright Water offers a solution. When cool, it is a tightly-bound polymer particle, less than a thousandth of a millimetre in diameter. However, when it reaches a specific warmer temperature, it suddenly expands tenfold – 'popping' like popcorn (see graphic, right).

Bright Water can be injected into the reservoir along with the water (diagram below right). The injection water is cooler than the reservoir and heats up most in the thief zones, which are bounded by unswept warm layers above and below. At the critical popping temperature the particles expand and block the rock pores of the thief zones. The flow of water is diverted from the thief zones into the adjacent layers to drive the oil out. Each batch of Bright Water can be designed so that it pops at a specific temperature for optimal placement.





Problem: Water injected into the reservoir mostly enters and sweeps thief zones rather than oil-bearing zones



Solution: Bright Water particles are injected along with the water and 'pop' in the warmer sections of the thief zones. This blocks the thief zones and redirects water to poorly swept oil-bearing zones, recovering more oil from the reservoir.

achieved a one per cent incremental recovery at a cost of less than $4 per barrel. Since then, over 600,000 additional barrels of oil have been recovered through Bright Water applications in Alaska. More extra oil is expected to follow over time.

In other locations, two treatments were conducted in 2007 in BP's Tangri field in Pakistan – oil production rate was doubled here – and in 2006-8 in six wells in Argentina, where BP is 60 per cent partner in Pan American Energy.

The success rate across the world is high, with additional oil coming from over 80 per cent of the treatments. Further applications are being evaluated by BP for fields in Egypt, Azerbaijan and offshore UK. If, for those fields selected, Bright Water can deliver incremental oil recovery of 1-3 per cent, the net benefit to BP could be more than 500 million barrels of additional oil.

The 'magic potion' envisaged over ten years ago by BP is living up to expectations.

Staying in control

Operating a large oil refinery so that it runs at maximum efficiency is a complex business – a wide array of process units carrying out different functions, but with multiple interdependencies between them, means that even a relatively minor change in the operating conditions of one part of the plant can have a knock-on effect in several other locations.

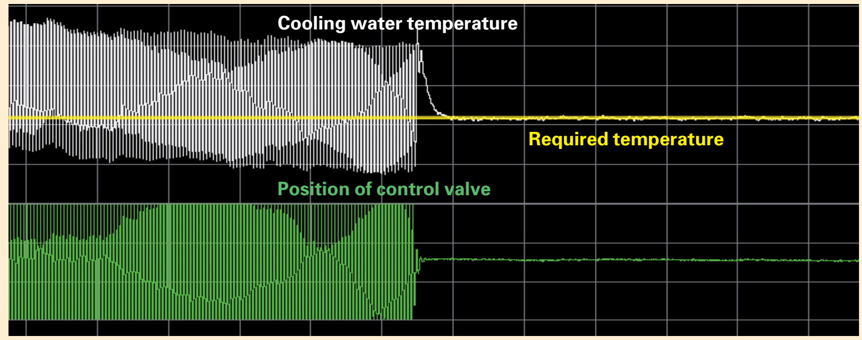
The primary means for keeping individual units and the whole refinery operating optimally is the control loop. This consists of instruments which measure parameters in the process units such as flowrates, temperatures and pressures, and use the data to adjust the setting of associated control valves in the loop in order to maintain the desired conditions in the process units. These controlling mechanisms lie at the heart of achieving the exacting specifications demanded for refined products, and also help to ensure that safety standards, equipment limits and environmental regulations are met.

A typical refinery requires well over 1000 control loops to operate it effectively. But ensuring every loop is performing at its best is a challenge – loops need to be 'tuned' correctly, they can become unstable, valves can be sized wrongly or can stick. For these and other reasons, control loops can actually introduce unwanted variability into unit operations.

Traditionally, process and process control engineers have relied on manual methods to identify poorly performing control loops, diagnosing the causes in response to operational issues as they arise – a time consuming, iterative and often difficult task. But now, BP is applying sophisticated software to the problem which is already having a positive impact at the company's many refineries around the world.

For the past few years, BP's *Refinery of the Future* team (*Frontiers*, April 2006) has been working closely with specialist controls supplier Expertune to enhance and deploy the company's proprietary PlantTriage performance supervision system. The system connects to a refinery's existing control system and extracts information about process operations, equipment and controls. It continuously monitors and analyses the health of the plant's control loops and associated valves, compares the findings against established standards and, where performance is sub-optimal, conducts further analysis to pinpoint the likely causes. The results are ranked by technical and economic importance and displayed as user-friendly graphics, enabling process control engineers to identify and tune poorly performing control loops quickly, thereby helping to increase production, save energy, reduce maintenance budgets and enhance overall plant safety.

PLANT TRIAGE SOFTWARE IN ACTION



The graphic above shows the operation of a cooling water temperature controller in a refinery coking plant. Use of PlantTriage software enabled BP to detect that the control loop was oscillating, leading to process inefficiency and wear on the control valve. The white trace shows the actual cooling water temperature fluctuations, compared to the required yellow 'setpoint' for the temperature. The green trace shows the position of the control valve, constantly changing as it tried to achieve the setpoint temperature. With the software in operation, the control loop is quickly stabilised to give a constant water temperature and steady valve position.

Millions of dollars per year may be saved in each refinery by deploying the new technology

'We have collaborated with Expertune to customise various aspects of the PlantTriage solution to suit BP's particular needs,' says Lakshman Natarajan, project leader in BP's refining technology group. 'For example, the communications protocol internal to the software was strengthened to meet BP's stringent IT security standards, and the report generation functionality was redefined to reflect typical functional roles and reporting structures in BP. Another new feature we influenced is the software's ability to identify loops which, by design, are not permanently in operation, so that the diagnostics are only applied when the loops are actually working. Efforts to improve benchmarking and diagnostic abilities of the software are also under way, and we are evaluating a method for quantitatively comparing the performance of similar process units between refineries. Our user feedback will be incorporated into future product releases.'

To date BP has deployed the technology in seven of its eleven refineries during the past two years – the scope ranges from several hundred control loops on two to three process units in one refinery, to over 2000 loops covering an entire refinery, making BP the leading user of PlantTriage. According to Natarajan, a 2000-loop installation can be commissioned within just four months, and the payback from improving refinery operations can be achieved in a similarly short timeframe. A 'best practices' document that captures lessons learned centrally has greatly aided rapid, large scale, standardised deployments.

The refineries are benefiting in several ways from the software systems. For instance, Texas City and Whiting refineries in the USA have been able to identify control loops that were in 'manual' mode rather than in 'automatic' mode as originally designed, thereby helping to enhance safety and environmental operations. In BP's refineries in Germany and Spain, the plants are focused on optimising performance. BP Germany has reported that the use of PlantTriage helped accelerate unit startup activities in 2008, by identifying a malfunctioning level sensor associated with a crude unit stripper and detecting several control valves that were oscillating.

While each instance of improving the performance of a control loop may seem small in isolation, taken together they paint a different picture – BP's refineries estimate that benefits of the order of $1–5 million per year are being realised in each refinery by deploying the technology and understanding how to use it to full advantage.

In the pipeline

When it comes to constructing pipelines, carbon steel has proved itself to be the most cost effective material for carrying hydrocarbon liquids and gases, be the pipelines above ground, on offshore facilities or subsea. But carbon steel has a major drawback – poor corrosion resistance. The alternative of using corrosion resistant material is very costly and because such materials are available from fewer suppliers, long supply lead times can occur. Hence in order to ensure a carbon steel pipeline remains reliable and retains the integrity demanded for safe operation, effective corrosion monitoring and periodic inspection are necessary requirements, along with the application of a corrosion inhibitor.

Corrosion monitoring is of particular importance in deepwater projects where pipelines sit out of sight on the seabed, often in several thousands of metres of water, carrying hydrocarbon fluids at high pressures and temperatures. Conventional techniques for effectively monitoring localised corrosion have limitations – either due to high pressures or temperatures inside the pipe, or by being unable to produce results with sufficiently high resolution or within a short timescale.

Driven by the fact that BP expects around 20 per cent of its offshore projects to be situated in deep water within15 years, and that around a third of these will experience high pressure, high temperature operating conditions, the company set to work in 2003 to find a superior solution to conventional corrosion monitoring. Working alongside corrosion monitoring specialist Cormon, BP's corrosion experts in the company's exploration and production business helped to direct and accelerate the development of a new technique, designed to cope with the rigours of deep water while also offering greater sensitivity in the detection of corrosion. The development, funded by BP, was put to the test in a successful trial at BP's Wytch Farm oil field in the UK during 2005–6, and is now commercially available.

Cormon's now-patented technology is known as RPCM – ring probe corrosion monitor – and uses an enhanced form of the established high-sensitivity electrical resistance (ER) method to measure metal loss.

RPCM takes the technique used in standard ER corrosion probes and applies this in an innovative ring configuration to enable 360° monitoring in a pipeline, compared with conventional single point monitoring. The rings are made from the same carbon steel material as the pipeline and are the same diameter, and sit in the line within a welded spool (see graphic above), enabling full fluid flow to pass through the line unimpeded, as can conventional pipeline 'pigs' used for cleaning and inspection.

The rings in the spool are machined into identical pairs – three pairs are typical – arranged such that one ring in the pair is exposed to the fluid flow while the other is a ceramic coated, isolated reference ring.

'In operation, a small current is applied to segments of the rings,' explains Colin Murdoch, who led the project for BP. 'The electrical resistance in the metal is measured within each segment and is directly compared with the reference ring. Metal loss will be detected as a change in resistance compared to the reference ring and can then be transmitted via simple electronics to the control room. The result is the ability to measure corrosion in real time, and with high accuracy.'

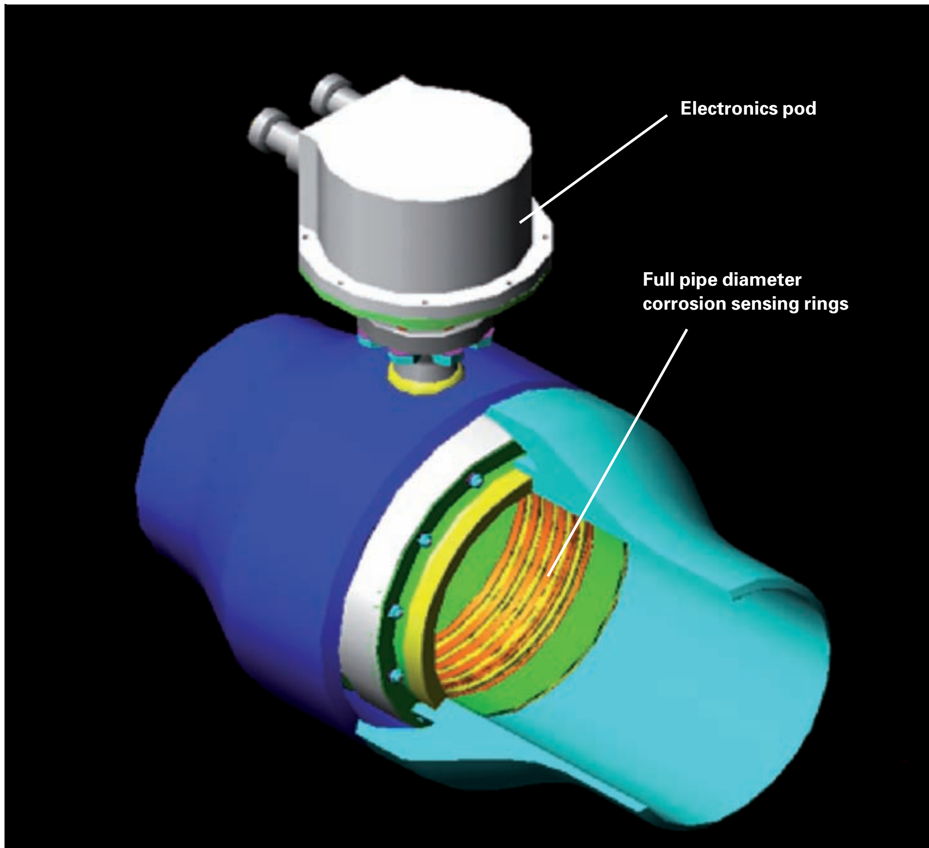
Precision monitoring of metal loss from the rings is made possible by Cormon's advanced, high resolution measurement system, which gives a resolution of 50 nanometres in subsea applications, some 3000 times greater than that available with other techniques. The device is capable of operating at up to 1000 bar and no on-site calibration is necessary. In addition to metal loss, RPCM measures and reports both temperature and pressure in the line.

BP's upcoming deepwater development in Block 31 offshore Angola has already ordered 21 RPCM units for the field's subsea pipelines. The advanced corrosion monitoring capability will enable 80 kilometres of 250mm diameter carbon steel pipe to be laid in water depths of around 2000m – if corrosion resistant alloy steel were used, this would add some $28 million to the pipeline cost.

While the RPCM technology was developed with deepwater pipelines as a target – and other BP deepwater projects could soon be in line to adopt it – the innovation is not limited to deep water and can equally well be applied in shallow water and onshore.

'With RPCM we now have the capability for real time, high resolution metal loss monitoring for high pressure and temperature flowlines in deep water,' concludes Murdoch. 'The ability to obtain instant feedback on a pipeline's condition is giving us the confidence to widen the operating envelope for low carbon alloy steels.' ■

INSIDE THE RING PROBE CORROSION MONITOR



Inside the RPCM, several pairs of carbon steel rings, made of the same material as the pipeline, sit in a welded spool in the line. One ring in each pair is exposed to fluid flow, while the other is isolated as a reference. Electrical resistance measurements detect metal loss by comparing the readings coming from the pairs of rings.