Subsea king

BP is recovering more oil from one of its deepwater fields through an ambitious subsea pumping project, pushing back engineering boundaries and opening up new opportunities for both the company and the wider industry. *Terry Knott* reports on the project's achievements

Deep beneath the waters of the Gulf of Mexico, two pioneering pumps are quietly carrying out an unusual task with great effect – capturing more oil from the hydrocarbon reservoir below. Sitting on the seabed in around 1600 metres of water, the pumps have been boosting production from the BP-operated King field since last November and are expected to recover 20 per cent more oil from the reservoir, extending the field's producing life and delivering many millions of barrels of additional oil.

'King represents a breakthrough in the world of multiphase subsea pumping,' says Gordon Stark, BP's projects programme director for deepwater projects in the Gulf of Mexico. 'The pumps and associated equipment are operating at almost twice the depth of the previous deepest multiphase pumps, and are also pumping the wellhead fluids to the host platform which is 27 kilometres distant, another step change compared to the previous record of 10 kilometres. This is a significant achievement in its own right, but also one which is proving a technology that will help unlock oil in other less viable deepwater fields.'

The output from oil wells normally peaks quite quickly once production from a field has started and then begins a steady decline as pressure in the reservoir falls. There are many tried and tested methods for slowing down the rate of decline, for example by injecting water into the reservoir to maintain pressure. The solution must take account of many factors, including reservoir characteristics and economics.

The fluids from subsea wells – a multiphase mixture of oil, gas and water – are normally transported to a host platform through a long flowline on the seabed for subsequent processing. The pressure at the well must be great enough to overcome the frictional losses in the line, and also the hydrostatic head of the water above the reservoir, in order to drive the fluids up onto the platform. If the reservoir energy drops below a certain level, the well will no longer flow under natural reservoir pressure – at which time it must be either abandoned or boosted to overcome the backpressure of the line.

'As we move into deeper and deeper waters round the world,' adds Stark, 'the energy required to lift the oil up from these depths is also increasing. Being able to add energy to the flow by subsea pumping will be a very useful tool to have in the toolkit of options for doing this. Pumping is likely to become increasingly important, not only as a way to enhance oil recovery but in some cases as an enabling technology to bring the development of particular oil fields into the envelope of economic viability.'

The King field, 90 kilometres from shore, originally came into production in 2001 through two subsea wells, tagged D5 and D6, which were joined in 2003 by D3, a well in the western part of the field (see diagram on page 36). Flowlines from the wells, located in water depths of 1525–1655 metres, carry well fluids to the BP-operated Marlin production platform 27 kilometres away, where oil, gas and water from King and other fields are separated and processed before export.

'At that time King's wells were still flowing under their own pressure,' notes Cathal Kelly, BP's project manager for the King subsea pumping project. 'But we knew from the outset that they would decline each year and that some form of boosting would be required. After a rigorous selection process, subsea pumping was chosen to do this. These wells were in the


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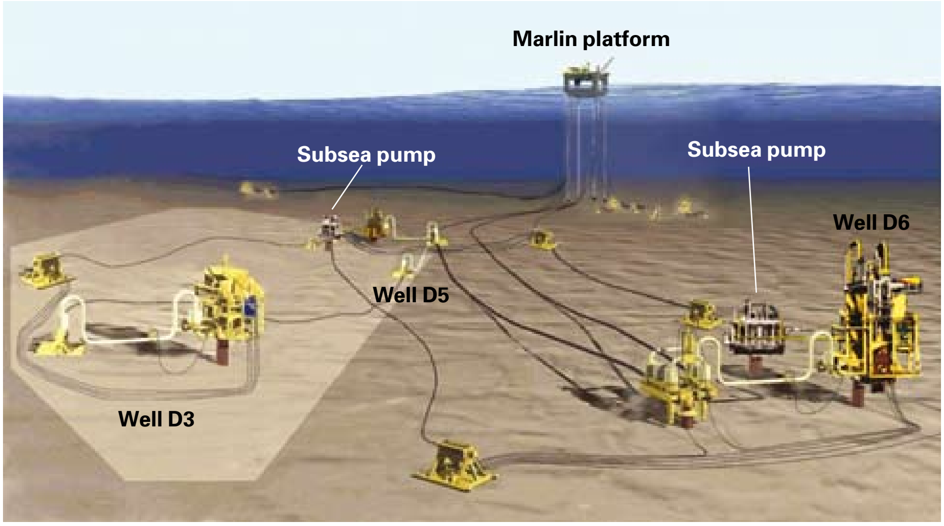


King subsea field layout showing three wells and two subsea pumps, tied back to the Marlin platform

top 20 producing wells from the thousands of wells BP operates worldwide, and were delivering around 40,000 barrels per day (bpd) of oil in 2003, so King provided an ideal test ground to demonstrate that subsea pumping was up to the task in very deep water.'

Subsea pumping is a key element in the industry's much sought-after 'dream' of being able to process wellhead fluids at the seabed, rather than having to transport them to a surface platform – a goal with which BP has long been involved (*Frontiers*, August 2002). While subsea pumping has been achieved in some offshore locations, the particular challenges presented by King – the remote operation of large rotating equipment driven by electric motors in very deep water without intervention for many years at a stretch – were viewed by BP as offering the chance to push toward the goal of full subsea processing.

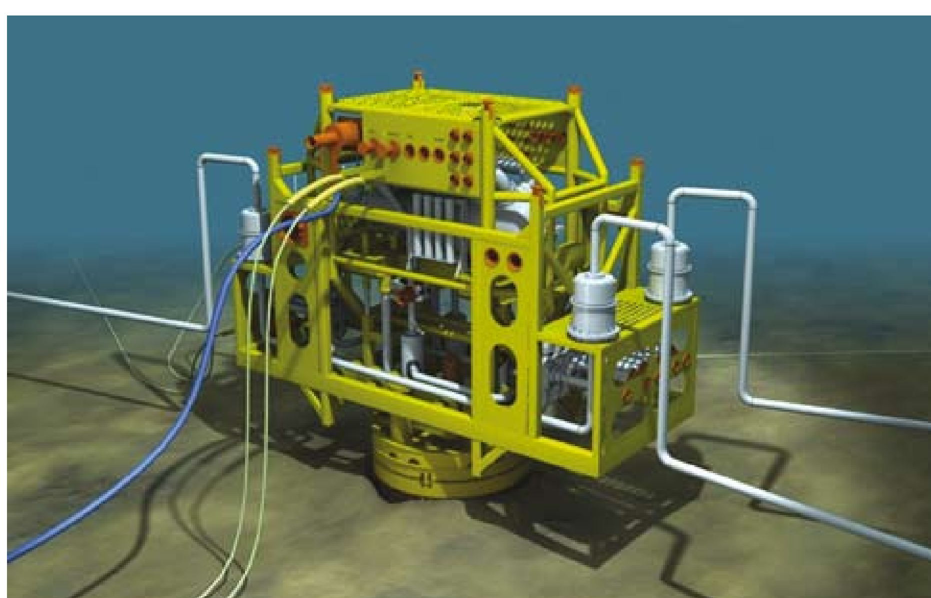
All pumped up

The King subsea pumping project, which would introduce multiphase subsea pumping into BP's technology portfolio as well as into the Gulf of Mexico for the first time, kicked off in 2004 with a price tag of over $100 million. The project called for two electrically driven pumps to be installed on the seabed, one to take the flow from D5 and D3, the other to handle well fluids from D6. The power to drive the pumps, each demanding 1.3 megawatts delivered at the pumps at 6.6 kilovolts, would come from Marlin, requiring additional equipment and modifications to be made to the platform topsides.

'The pumps had to meet a tough performance specification,' Kelly points out. 'In addition to operating at twice the water depth of any previous subsea pumps, they each have to be able to handle a multiphase flow of up to 75,000bpd which sometimes might contain up to 99 per cent gas volume fraction and sand from the reservoir, withstand the shut-in pressure at the wells of 345 bar, and raise the pressure of the well fluids by 50 bar. We were also seeking a reliability of 95 per cent, aiming for a mean time between failures of 3.5 years or longer.'

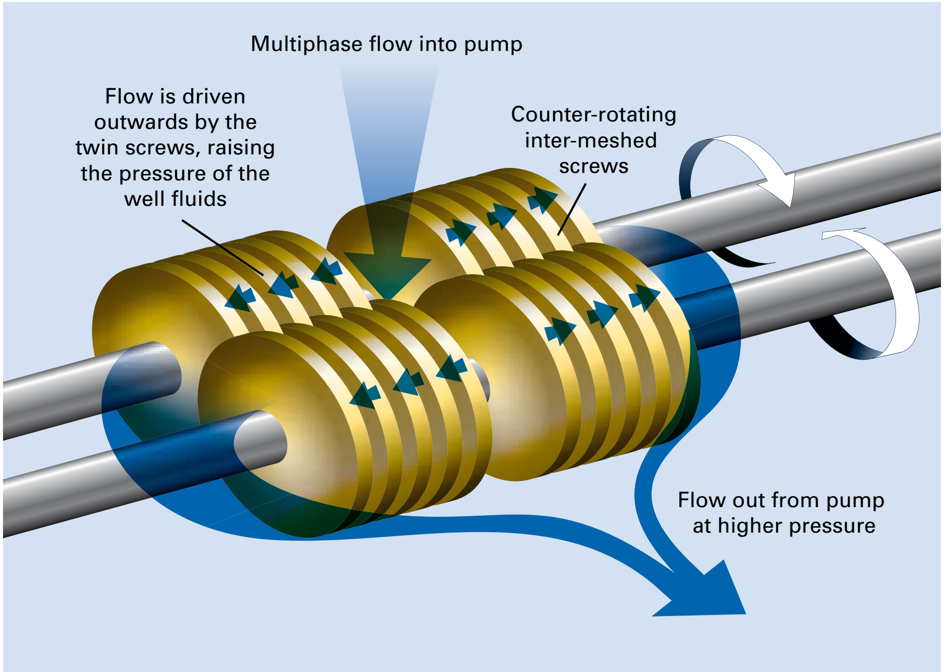
As the integrator of a wide range of subsea components and systems, the BP project team adopted the policy of employing as many equipment items as possible that were already proven and qualified by the company, for example subsea valves and controls. But at the same time, it was recognised that to achieve the ambitious goals set for King, several technology gaps would need to be bridged.

'We were working to introduce new technology, much of which required further development by equipment vendors, and qualification and testing by BP,' Kelly explains. 'As such, this carried risks. To manage these risks we implemented a technical risk assurance process at the start of the project which tracked each individual component of any new technology solution right through its life, highlighting any issues as they arose and making sure all components were keeping in step. In combination with BP's system for



Each subsea pump station is 9 metres long by 8 metres high, weighs 88 tonnes and is mounted on a foundation pile in the seabed

HOW THE TWIN-SCREW PUMP WORKS



running major projects, this proved to be invaluable in making the project a success.'

The pumps for King were selected in 2005, following a competitive development programme between pump vendors. The MultiBooster pumps chosen are a proprietary design from Aker Kvaerner that had been in development for some years, but at that point had not been proven in an offshore field – a 'prototype' MultiBooster pump was subsequently installed by another operator in shallow water in the Lyell field in the North Sea in December 2005.

The heart of the MultiBooster is a twin-screw positive displacement pump (see diagram above) manufactured by Bornemann in Germany, a robust design widely used on platform topsides and capable of handling the changing demands of multiphase flow. To ensure the pumps would match the rigours of the duty required at King, BP worked closely with Aker Kvaerner to upgrade and qualify several critical components within the pump, among them the seals and lubrication system.

'The pumps seals are designed to keep the high pressure wellhead fluids inside the pump,' says Kelly. 'But the pump experiences high external pressure too due to the water depth, which means that if the pump is not running the pressure comes on the seals from outside. This is not usually the case in shallow water pumps, so we enhanced the sealing systems for King to work in both directions.

'The localised lubrication system for the pump bearings is another critical system that was upgraded. The lubricating oil – the life blood of the pump – is held at 10 bar above the well pressure to prevent ingress of fluids into the lube oil, which is also cleaned to an exceptionally high specification to ensure it is dry and free from particulate matter that could cause unnecessary wear on the bearings. Keeping the bearings in good condition is the key to achieving a long mean time between failures.'

The pumps are housed in two modular pump stations, complete with electrical drive motors and ancillary systems, each weighing 88 tonnes and measuring 9 metres long, 3.5 metres wide and 8 metres high – substantial subsea structures. The systems are designed for operation in up to 3000 metres of water, giving the pump design the ability to be deployed in any current deepwater development in the industry. The main parts of each module – the pump is the heaviest at around 60 tonnes – can be retrieved individually to the surface by a medium-sized offshore service vessel, assisted underwater by remotely operated vehicles (ROVs). A full set of spares is available for the pumps; BP has a predictive maintenance programme in place to avoid breakdowns, and as a backup a third complete pump stands in readiness at BP's onshore base in Houma, Louisiana, which could be changed out with an offshore pump in two to three weeks.

Technology upgrades

As important as the pumps are to the project, many other components, large and small, required technology development programmes to qualify them for King.

One such major equipment item is the umbilical – the seabed connection from Marlin to King, running alongside the flowlines, which conveys several different services to the subsea pumps, all neatly packed into a protective 180mm diameter bundle snaking across the seabed. The umbilical contains standard elements encountered in many of the industry's subsea umbilicals, namely: super duplex stainless steel tubes for transporting hydraulic fluid for the operation of valves and other equipment items on the pump modules; lubricating oil top-up and chemical lines; low voltage electrical cables to power the subsea control system; and fibre optic cables for transmitting control signals to the pumps and receiving back information. The pump modules contain an advanced condition monitoring system to check continuously on the behaviour and status of numerous components. But the umbilical also contains six high voltage electrical cores, rated to 24 kilovolts, which provide three-phase supplies to the pumps – when the umbilical reaches the first pump it 'splits' and reduces in size to carry the services to the second pump, some four kilometres away.

'With the exception of the high voltage cables, all the services inside the bundle are duplicated for redundancy,' observes Kelly. 'One interesting phenomenon is that the high voltage cables – the voltage on Marlin is 9 kilovolts, dropping ›

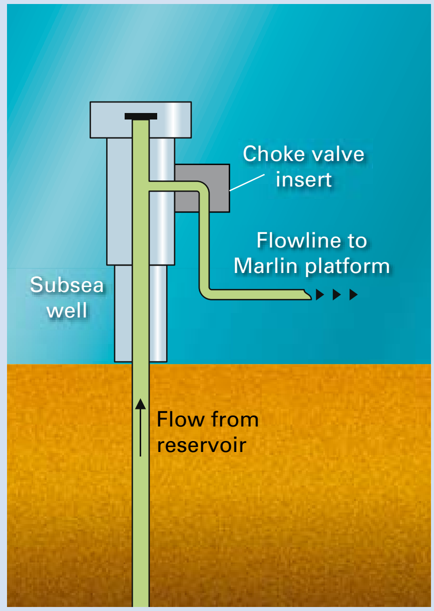
Installation vessel *Normand Cutter* carrying the two King pumps and umbilical reel

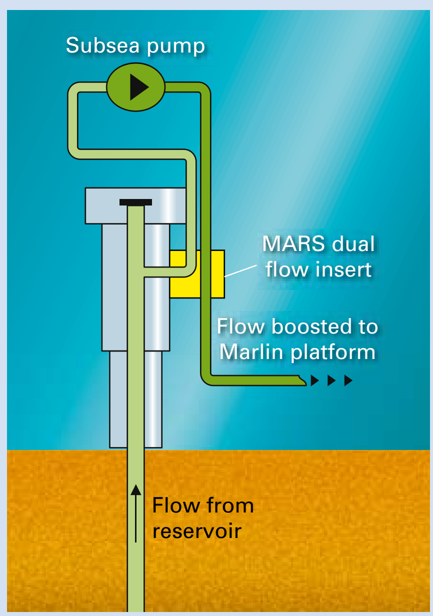
NEW LIFE FROM MARS

The King subsea pumping project also saw another innovative engineering solution make its debut. MARS (Multiple Application Re-injection System), developed by DES Operations in Aberdeen with support from BP and others, provides a universal interface with subsea wells so that other equipment, for example pumps, meters or separators, can be added at any time during a field's life with minimum risk and disruption to production.

This is achieved by replacing the retrievable choke valve insert (graphic top right) normally fitted to a subsea well with a MARS dual flow insert. The dual flow insert (graphic below right) allows flow from the well to be directed externally to new subsea hardware and then returned into the existing flowlines leaving the well.

Two MARS units were installed for the King project, one for each multiphase pump. The photo below shows one of the units being lowered into the sea during installation. MARS enabled the King subsea pumps to be added into the flowpath of the well fluids without having to drain down the long flowlines running to the Marlin platform, thereby minimising production downtime.





› to 6.6 kilovolts at the pumps due to power losses over the long distance – can induce a fluctuating voltage into the 240 volt electrical control lines caused by their proximity in the umbilical. To counter this fluctuation, which could more than double the control voltage, there is an electronic filter at the pumps to "clean up" the low voltage before it enters the subsea control module.'

The umbilical, supplied by Nexans, was put through an extensive engineering and qualification programme to investigate its performance characteristics as the deepest dynamic umbilical yet to be installed – that is, it hangs from Marlin in a long catenary curve reaching vertically down almost 900 metres before it touches the seabed. As Marlin is a floating tension leg platform it drifts around its moored location as sea conditions change, hence the umbilical – which weighs over 50kg per metre of its length in air – and its contents are subjected to continuous movement and therefore changing loads and potential fatigue.

The high voltage power is connected to the pumps through wet mateable connectors, which are hooked up to the pumps on the seabed using a deepwater ROV. The connectors, supplied by Tronic, were upgraded and qualified for King, modified not only to accommodate the increased operating voltage and water depth, but also repackaged for deepwater ROV connection and simplified for ease of recovery should this be required.

The two pumps are operated at different speeds to suit the King well conditions. The rate of the pumps is controlled by variable speed drives located on Marlin in a 55 tonne topsides module comprising major equipment items, for which BP again worked closely with the supplier Siemens to ensure the demands of the King subsea pumps would be met – variable drives have not been used at such long distances before.

'All monitoring and control operations for the pumps are carried out from Marlin,' adds Kelly. 'In addition, the systems are also tied into BP's Advanced Collaboration Environment in Houston so we can see what is going on from anywhere in the world.' (*Frontiers*, December 2006.) As if to emphasise the point, he turns to his laptop – in London at the time – and quickly logs into the full picture of what is happening at the pump stations all those kilometres away and metres below the sea.

The pump modules and associated equipment were installed through the summer of 2007, with the pumps coming into operation on schedule in November of that year. They are expected to run until 2013 with the current King wells, and longer if more tie-backs are added to deplete the King reservoir as far as practicable.

'Both pumps came up and ran first time,' notes Stark, 'which is a huge accolade to the whole team, vendors included. They have not stopped since, except for the odd occasion when the Marlin platform has not been in operation.'

The positive impact of the project is already evident. BP expects to recover oil from the southern part of the King field, a few kilometres distant, by connecting a new well into one of the existing subsea pumps. Without subsea pumping to help recover more oil, King South would have been less commercially viable.

'There is no doubt that the success of the King subsea pumping project will have several benefits for BP and the industry overall,' concludes Stark. 'We have proven deepwater multiphase subsea pumping, which is a dramatic technology step towards full subsea processing; choice in the vendor supply market has been improved and widened; and BP has another option when considering existing and new field developments. And of course, we are winning a lot more oil from the King reservoir.' ■

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