EOR: a key mechanism for meeting tomorrow's energy needs

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The International Energy Agency (IEA) has recently developed a reference scenario for oil production which indicates that by 2030 half of the estimated total 100 million bbl/day will come from reservoirs and fields that are currently not yet developed or found. This includes Enhanced Oil Recovery (EOR).

A second IEA study, from 2008, concludes that the production-weighted average decline rate for oilfields is increasing from some 7 per cent today to 9 per cent by 2030, which means that it becomes even more urgent to develop the world's remaining resources. The conclusion is therefore that sustained investment is required to reverse the rapidly declining production. Although these more rapid declines might suggest depleted fields, a lot of oil continues to be left in the reservoirs and Improved and Enhanced Oil Recovery are the key mechanisms to increase ultimate recovery.

If we look at the recovery status of a portfolio of fields, we can introduce the concept of reservoir complexity, a number that indicates how complex a reservoir is in terms of geology and fluid characteristics. Fields with low complexity often have a high ultimate recovery, fields with a high complexity generally have a lower ultimate recovery. A systematic analysis including benchmarking allows us to segment the portfolio into a few groups; one where we speak of top quartile recovery and a number of groups of reservoirs that fall short of this. This type of analysis offers a significant opportunity to screen and plan for improved recovery.

Enhanced Oil Recovery Mechanisms

The physics of oil recovery essentially points to only two major factors that need to be addressed to increase ultimate recovery. The first is lowering the residual oil saturation by changing the wettability or interfacial tension and the second is maximising the sweep efficiency through better well placement or mobility control.

Addressing the geological complexity as well as the fluid characteristics often requires a customised solution. That is why there are a significant number of different EOR processes, of which the optimum has to be selected for each given reservoir. An often heard phrase is "Fluid properties and geology determine the technology".

In the figure to the right a so-called maturation or S-curve with EOR processes and their technical maturity is depicted. The top right contains a number of so-called mature EOR technologies, such as miscible gas injection, cyclic steam soak, vertical stream drive and polymer flooding, all of which are well established and can be implemented in many situations without significant adaptation.

In the middle are the processes requiring a significant amount of optimising and often field trials to get the correct full field design. These include Alkaline Surfactant Polymer (ASP) flooding, Enhanced Polymer Flooding, In-Situ Combustion (ISC), High Pressure Steam Injection (HPSI), Steam-Assisted Gravity Drainage (SAGD) and Designer Waterflooding.

The technologies in the bottom-left group are immature but very promising and have proven their worth in extensive laboratory experiments and model studies. These require further de-risking in field trials before embarking on full field developments. This category includes catalytic or heater oil upgrade and conversion in the subsurface, use of solvents, gas foams and hybrid processes.

Applications

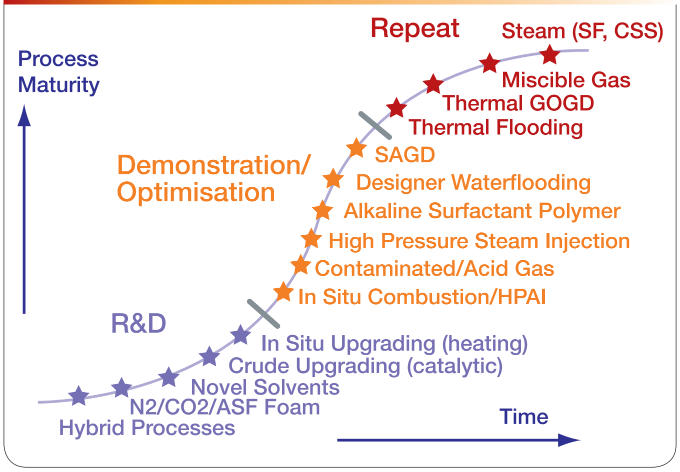
During the last several years Shell and its affiliates have initiated a significant number of Enhanced Oil Recovery projects covering chemical, thermal and miscible flooding applications in a variety of geological and hydrocarbon settings.

In Syria, successful field trials were conducted with the designer waterflood concept, where the salinity and ion composition of the injection water is designed such that the wettability of the rock is changed to reduce the residual oil saturation. Residual oil saturation reductions of 14 per cent around the well-bore were demonstrated in these trials and our Joint Venture in Syria is now embarking on large-scale developments.

The concept is not totally new. Some 10 years ago we saw the positive effect of switching from injecting saline produced water to fresh water with a clear oil bank response in the production wells in combination with low-salinity water breakthrough.

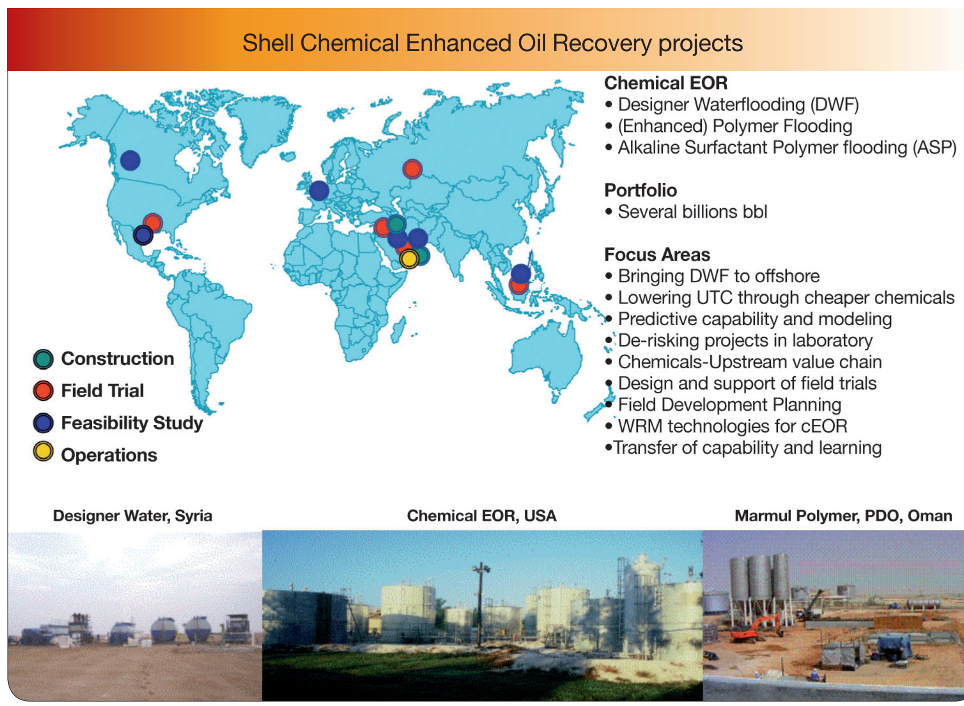
A series of Alkaline Surfactant Polymer trials were also

Main EOR Processes and Maturity



conducted in a number of fields in the Middle East and Russia. The successful outcome of these single well tests is a near complete oil de-saturation around the well-bore, in line with the lab tests. Joint Ventures are now progressing plans for continuous injection tests in patterns as a final step before full field implementation.

Key in de-risking and sanctioning these type of EOR projects is a far more detailed understanding of the fundamentals in rock and fluids physics and chemistry that each have a major impact on the ultimate recovery. This required a significant upgrade of our experimental capability to measure relevant rock and fluid properties, as well as the ability to visualise and model the EOR processes at various geological and time scales. State of the art experimental facilities have been built to enhance visualisation and understanding of flow processes in cores, as well as to measure accurate physical and chemical properties under realistic in-situ conditions.



Achieving the technical optimum recovery is not the only criterion for successful field development. Enhancing energy efficiency and minimising the CO_2 footprint have also become important drivers and a number of recent advances have been made that will lead to further improvements in the Unit Technical Cost (UTC) and environmental footprint.

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The shell proprietary reservoir simulator and modelling toolkit has been upgraded to include relevant EOR processes and rock/fluid interactions in sufficient detail, covering for example In-Situ Combustion, Polymer floods, Designer Waterflooding, Alkaline Surfactant Polymer flooding, Thermally Assisted Gas-Oil-Gravity-Drainage, solvent, and hybrid applications at various modelling scales, ranging from the pore and core scale to full field simulations.

Smart Fields

So far only enhanced recovery mechanisms have been addressed. This is, however, only half of the solution to obtain maximised ultimate recovery. Top quartile Well and Reservoir Management (WRM) is equally important, as many leading operators have demonstrated. WRM for EOR however also requires a next generation of surveillance and WRM tools that are being developed as part of the Smart Fields concept.

Smart fields technology, also referred to in the literature as 'e-field' or 'digital oilfield' technology, involves an integrated approach (the 'value loop' as indicated in the picture on the right) covering data acquisition, the use of reservoir and production system models, decision making and automation and control in the assets in a fully integrated and closed-loop fashion. The measurements may originate from sensors in smart wells, but could also involve simple surface measurements from conventional wells, or originate from other sources such as time-lapse seismic or other areal surveillance methods.

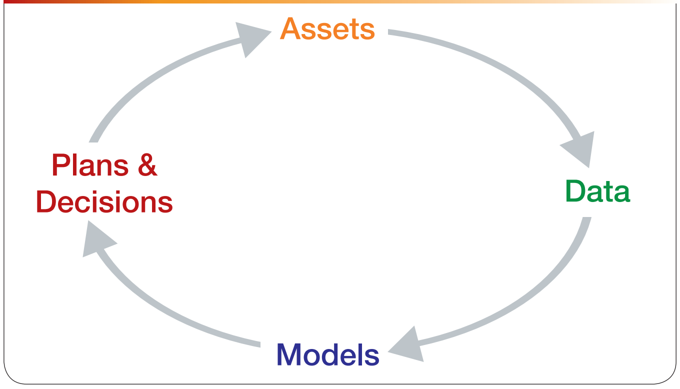
Extending the Smart Field concepts to EOR requires definition of the appropriate levels of smartness for each of the Smart Field Life Cycle: data acquisition, modelling, integrated decision making and operational field management with a high level of integration and automation. For operational EOR projects mainly targeting improved sweep efficiency and operational cost reductions, new surveillance methods and technologies were developed and deployed in collaboration with oil and gas industry service providers to obtain better and cheaper data.

Example are the use of various geophysical methods to measure (steam) flood performance, high-temperature internal control valves to improve steam injection conformance, fibre optic sensing applications or advanced tracer tests.

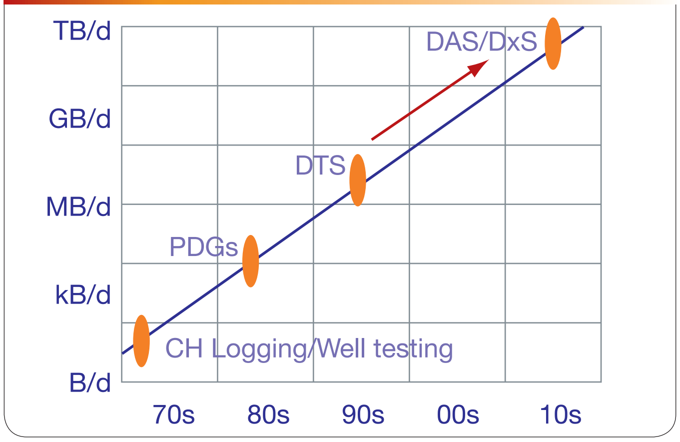
Down-hole fibre optics developments for the oil and gas industry are going through a revolution and will see more mainstream applications for a variety of applications in the next decade. With this development comes the PetaByte challenge. Whereas in the last century fibre optics applications such as distributed temperature sensing (DTS) applications had a data rate of several MegaBytes per day, the recently tested down-hole acoustic applications (DAS) produce over a million times more data in the order of several TeraBytes per day. The figure to the right shows the data volume per day in bytes per day for the last several decades. It shows a 1000 fold increase in data volume per decade for a typical measurement in a well. To handle this data volume increase we require a change to the way we acquire, analyse, and store data. Apart from the more obvious improvements in hardware capacity, also changes are foreseen in smarter exception based surveillance and real-time data filtering and processing to avoid storing and analysing all data.

An important part of the Smart Fields concept is closed loop reservoir management to ensure the data gathered in the operations phase is used to improve reservoir models and speed-up the field management cycle. Novel mathematical optimization and control methods are rapidly maturing to assist automatic history matching, high-grading geological reservoir models and reducing the remaining uncertainties, leading to better well offtake or injection policies, high-grading geological realisations as well as improving insights in what key parameters drive the objective function (such as Net Present Value (NPV), cumulative reduction) over the full life cycle, rather than at discrete points in time.

The Smart Fields Value Loop



The PetaByte Challenge:
1000 fold data volume increase per decade



The much faster turn-around cycle resulting from the tighter coupling of real-time data with faster and more responsive reservoir models will result in better and faster decisions. Use of advanced automation and control solutions at the surface (e.g. robotics & automation) and down-hole (e.g. internal control valves) will result in much quicker implementation of the decisions as well. The goal is to reduce the reservoir management feedback loop from months to days. In that way we can optimise reservoir sweep and reduce life-cycle costs, and hence achieve much better ultimate recovery at lower cost levels.

Conclusions

Enhanced Oil Recovery will become an increasingly important part of the oil supply due to more rapidly depleting fields under primary and secondary recovery schemes.

Addressing the geological complexity as well as the fluid characteristics often requires a customised EOR solution for each given reservoir. Top quartile well and reservoir management for EOR projects requires the application of new technologies and workflows to accommodate higher data volumes as well as manage more complex recovery processes.

Apart from pursuing improvements in ultimate recovery, energy efficiency and the CO_2 footprint have become important drivers, and a number of recent advances have been made that will lead to further improvements in Unit Technical Cost (UTC, $/bbl) and environmental footprint.

Dissemination of knowledge, workflows and experience across the various projects has resulted in a global EOR approach shortening the duration of screening, feasibility and development efforts as well as reducing the need for field trial or pilots, overall reducing the cycle time for EOR projects. ❑