EOR- Challenges and opportunities (PAPER 1)

julio josue

Enhanced oil recovery: challenges & opportunities

BY SUNIL KOKAL AND ABDULAZIZ AL-KAABI
EXPEC ADVANCED RESEARCH CENTRE, SAUDI ARAMCO

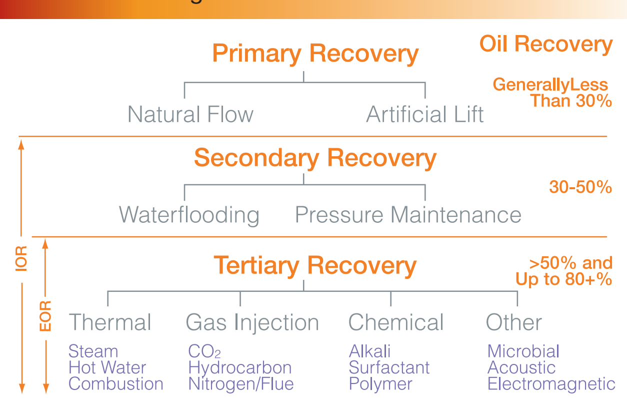
Recovery is at the heart of oil production from underground reservoirs. If the average worldwide recovery factor from hydrocarbon reservoirs can be increased beyond current limits, it will alleviate a number of issues related to global energy supply. Currently the daily oil production comes from mature or maturing oil fields and reserves replacement is not keeping pace with the growing energy demand. The world average recovery factor from hydrocarbon reservoirs is stuck in the mid-30 per cent range. This challenge becomes an opportunity for advanced secondary and enhanced oil recovery (EOR) technologies that may mitigate the demand-supply balance.

This paper presents a big-picture overview of EOR technologies with the focus on challenges and opportunities. The implementation of EOR is intimately tied to the price of oil and overall economics. EOR is capital and resource intensive, and expensive, primarily due to high injectant costs. The timing of EOR is also important: a case is made that advanced secondary recovery (improved oil recovery or IOR) technologies are a better first option before full-field deployment of EOR. Realisation of EOR potential can only be achieved through long-term commitments, both in capital and human resources, a vision to strive towards ultimate oil recovery instead of immediate oil recovery, research and development, and a willingness to take risks. While EOR technologies have grown over the years, significant challenges remain. Some of the enablers for EOR are also discussed in this paper.

EOR/IOR definitions

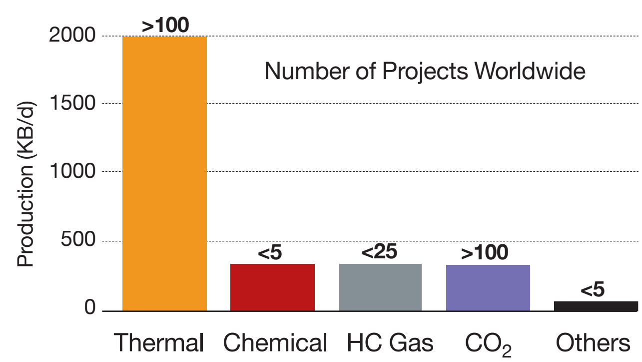
At this stage, it is important to define EOR. There is a lot of confusion around the usage of the terms EOR and IOR. Figure 1 shows these in terms of oil recovery, as defined by the Society of Petroleum Engineers (SPE)[1,2]. Primary and

Figure 1: EOR/IOR definition



From SPE-SPE-84908, 87864

Figure 2: Worldwide EOR production rates



(Data from Oil & Gas Journal, SPE, and other sources)

secondary recovery (conventional recovery) targets mobile oil in the reservoir and tertiary recovery or EOR targets immobile oil (that oil which cannot be produced due to capillary and viscous forces).

Primary, secondary and tertiary (EOR) recovery methods follow a natural progression of oil production from the start to a point where it is no longer economical to produce from the hydrocarbon reservoir. EOR processes attempt to recover oil beyond secondary methods, or what is left. Recovery, especially EOR, is closely associated with the price of oil and overall economics. On average, the worldwide recovery factor from conventional (primary and secondary) recovery methods is about a third of what was originally present in the reservoir. This implies that the target for EOR is substantial ($^2/_3$ of the resource base). Improving the recovery factor can be achieved by deploying advanced IOR technologies using best-in-class reservoir management practices, and EOR technologies.

Worldwide EOR oil production

The total world oil production from EOR has remained relatively level over the years, contributing about 3 million barrels of oil per day (Figure 2), compared to ~85 million barrels of daily production, or about 3.5 per cent of the daily production. The bulk of this production is from thermal methods contributing ~2 million barrels of oil per day. This includes the Canadian heavy oil (Alberta), California (Bakersfield), Venezuela, Indonesia, Oman, China and others. CO_2-EOR, which has been on the rise lately contributes about a third of a million barrels of oil per day, mostly from the Permian Basin in the US and the Weyburn field in Canada. Hydrocarbon gas injection contributes another one third of a million barrels per day from projects in Venezuela, the US (mostly Alaska), Canada and Libya. Hydrocarbon gas injection is mostly implemented where the gas supply cannot be monetised. Production from chemical EOR is practically all from China with the total worldwide production of another third of a million barrels per day. Other more esoteric methods, like microbial have only been field-tested without any significant quantities being produced on a commercial scale.

These numbers were taken from the SPE literature, Oil and Gas Journal[3] and other sources, and probably are a little conservative because some of the projects are not reported, especially the new ones. A better estimate of the total EOR production will be about 10-20 per cent higher than the 3 million per day figure quoted above.

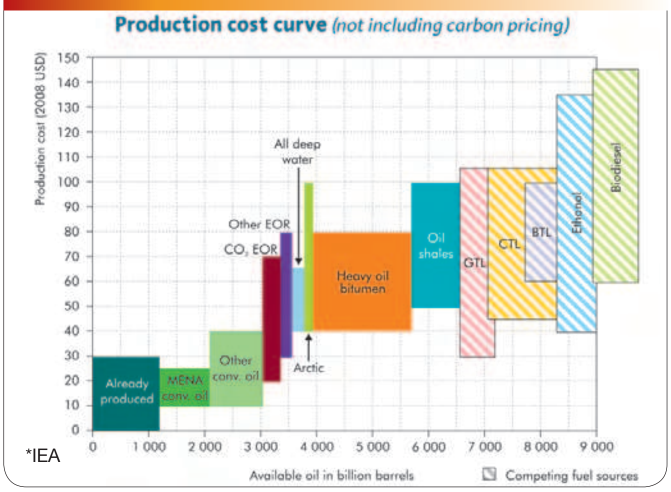
EOR current status

The global average or aggregate recovery factor from oil reservoirs is about a third. This is considered low and leaves a substantial amount of oil underground. A global effort has been under way for some time to increase this number and one reason for its failure is the relationship between oil price and resource availability. Figure 3, from the International Energy Agency, shows the connection between production cost and oil resources and the cost of converting them to reserves.

The cheapest injectant for producing oil is water. As long as companies can produce oil by injecting water, they will continue to do so. Another ~2 trillion barrels of oil can be produced with the price of oil below US$40 (2008 $) per barrel. Many of the EOR technologies kick in when the price of oil is between US$20-80 per barrel. In the early 1980s there was tremendous interest generated in EOR due to oil price escalation. The number of EOR projects and R&D investment peaked in 1986. The interest fizzled out in the 1990s and early 2000s with a collapse in the price of oil. A renewed and growing interest has taken hold during the past 5 years as the price of oil has increased again. Figure 4 shows this relationship between EOR projects and oil price. There is a lag between the price of oil and EOR projects. In the last price escalation, interest was mostly in the US but this time the interest in EOR projects is global.

Besides the link of EOR to oil price, the projects are generally complex, technology-heavy and require considerable capital investment and financial risks. The risks are aggravated with the fluctuations in the price of oil. The unit costs of EOR oil are substantially higher than those of secondary or conventional oil. Another challenge for EOR projects is the long lead time required for such projects. Typically, it may take several decades from the start of the concept – generating laboratory data and conducting simulation studies – to the first pilot and finally, full commercialisation. Two examples are given here, one each for thermal (Figure 5) and miscible gas injection (Figure 6)

Figure 3: Oil price and resources availability



projects. While there has been some discussion in the literature of applying or deploying EOR at an early stage of a reservoir's life, this is generally difficult, and not necessarily the best option, due to the risks involved and lack of data availability, that can easily be obtained during the secondary stage of recovery.

The two most popular EOR methods as discussed below are thermal (steam) and miscible gas injection, which are mature technologies. In chemical EOR, polymer injection is reaching commercial status (Figure 7). Acid gas injection, in-situ combustion (including the newer high-pressure air injection, (HPAI)) and combination chemical flooding are still in the technology development stage. Microbial, hybrid and other novel technologies are in the R&D stage. This compounds and restricts the application of EOR for a given field. If thermal and miscible gas injection methods are applicable to a given reservoir, then the decision to move forward is a little easier. If not, the decision is harder, and depends on the availability of injectant, economics and other factors previously discussed.

EOR technology matrix

EOR methods are classified by the main mechanism of oil displacement[4-9]. There are really just three basic mechanisms for recovering oil from rock other than by water alone. The methods are grouped according to those which rely on (a) A reduction of oil viscosity, (b) The extraction of the oil with a solvent, and (c) The alteration of capillary and viscous forces between the oil, injected fluid, and the rock surface. EOR methods are therefore classified into the following three categories:

- Thermal methods (injection of heat);
- Miscible gas injection methods (injection of a solvent);
- Chemical methods (injection of chemicals/surfactants).

Thermal EOR

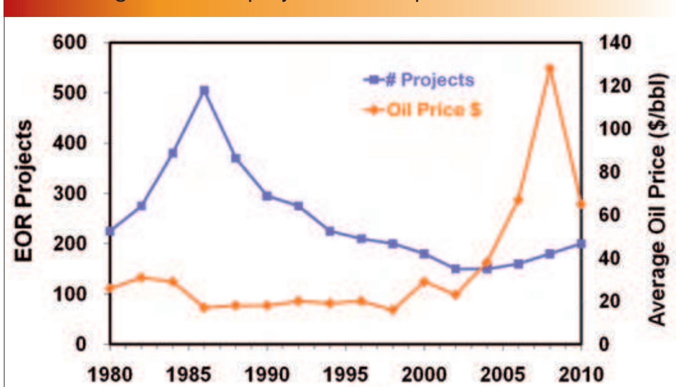
Thermal EOR methods are generally applicable to heavy, viscous crudes, and involve the introduction of thermal energy or heat into the reservoir to raise the temperature of the oil and reduce its viscosity. Steam (or hot water) injection and in-situ combustion are the popular thermal recovery methods. Three common methods involving steam injection are cyclic steam stimulation (huff and puff), steam flooding and steam assisted gravity drainage (SAGD). In-situ combustion involves the injection of air, where the oil is ignited, generates heat internally and also produces combustion gases, which enhance recovery.

Steam injection has been most popular in heavy oil sand reservoirs with ongoing projects in Alberta (Canada), Venezuela, California, Indonesia, the former Soviet Union, and Oman[3]. Lesser (small commercial or field trials) have been reported in Brazil, China, Trinidad and Tobago, and other countries. SAGD has been mostly popular in the oil sands and extra-heavy crudes of Alberta, and tested in Venezuela with limited success. Several hybrid versions of SAGD have been reported but remain at field-trial levels only[6].

In-situ combustion projects, not as popular as steam flooding, have been reported in Canada, India, Romania, and the US. It has been applied mostly to heavy oil sandstone reservoirs. A new version, HPAI, for light crudes has been gaining in popularity over the past 10 years and shows potential, especially in light oils and low permeability carbonate reservoirs. Several projects have been concentrated in the north-western US and Mexico is also considering HPAI for one of its fields.

The future of thermal methods is perhaps the brightest for the more difficult heavy oil and tar sands resources. Currently, SAGD is primarily being applied in Alberta and several hybrid technologies (e.g. injection of solvent with steam) are being tested. This technology is ripe for being applied in other parts of the world. Air injection, if tamed and understood, may also have applications in light oil reservoirs as the injectant supply is plentiful. Steam flooding too has been tested successfully in light oil reservoirs that satisfy certain criteria (depth < 3,000 ft, oil saturation-porosity product > 0.1).

Figure 4: EOR projects and oil price correlation



Data from Oil & Gas Journal, EIA and other sources

Miscible gas EOR

Gas injection, especially CO_2, is another popular EOR method, and is applicable to light oil reservoirs, in both carbonates and sandstones. Its popularity is expected to increase for two reasons: increased oil recovery through miscibility and disposal of a greenhouse gas. There are over 100 commercial CO_2-EOR projects, the bulk of them concentrated in the west Texas carbonates of the Permian Basin in the US. Their success has partially been due to the availability of low-cost natural CO_2 from nearby fields and reservoirs. Another important CO_2-EOR project is Weyburn-Midale in Saskatchewan (Canada) where CO_2 is sourced from a gasification plant in North Dakota and piped across the border. Many other CO_2-EOR projects are on the drawing board as a result of environmental reasons (sequestration).

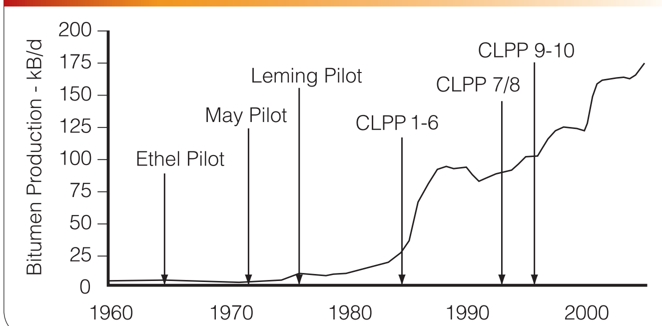
Hydrocarbon gas is also an excellent solvent for light oil reservoirs, if available. In places where it cannot be monetised (no local market), it can be injected into an oil reservoir for EOR. This has been the case in Alaska, Venezuela, Libya and Canada. Other gases, such as nitrogen (Cantarell field, Mexico) and acid or sour gases (Tengiz field, Kazakhstan, Harweel field, Oman and Zama field, Canada), have, or will be injected, although to a lesser extent than CO_2 and hydrocarbon gases. The current challenges in gas injection as an EOR method are gravity segregation, and most importantly, availability of a low-cost gas source.

The future of gas injection lies primarily with CO_2. There is a concerted effort around the world to reduce carbon capture costs. Once this becomes feasible, injection of CO_2 may become widespread in light oil reservoirs. Hydrocarbon gas injection has limited potential except where there is no market for it.

Chemical EOR

In chemical EOR or chemical flooding, the primary goal is to recover more oil by either one or a combination of the following processes: (1) Mobility control by adding polymers to reduce the mobility of the injected water, and (2) Interfacial tension (IFT) reduction by using surfactants, and/or alkalis. Considerable research and pilot testing was done in the 1980s and a string

Figure 5: Timing of EOR: Cold Lake – Canada



of projects were implemented during that time, mostly in the US. Consequently, none of those projects were successful, at least economically. The only place where chemical EOR has been successful, especially polymer, is in China over the last decade. Based on the success in China and the recent increase in oil price, a renewed vigour has come into chemical EOR and several field trials and pilots are ongoing, and/or on the drawing board. The famous one is the Marmul field in Oman. Other projects are in Canada, the US, India, Argentina, Brazil, Austria and Argentina. Surfactant injection has not produced any successes and remains challenging, especially in a high salinity, high temperature environment. Alkalis, although cheap, bring along a string of operational headaches (scaling, emulsions, plugging, etc.). Nearly all of the polymer floods have been implemented in sandstones, and carbonates remain a major challenge.

Chemical EOR faces significant challenges, especially in light oil reservoirs. One of the reasons is the availability, or lack of, compatible chemicals in high temperature and high salinity environments. Figure 8 shows the current limitation on a salinity-temperature plot. R&D will play a critical role in the future of chemical EOR.

Advanced IOR and best practices

A good 'first' option for any reservoir is to maximise secondary stage recovery. Advances in technology and the utilisation of best-in-class reservoir management practices will enable the maximisation of water flooding oil recovery before deploying EOR. Saudi Aramco is perhaps the world leader in optimising the recovery from its reservoirs through prudent reservoir management practices. Some of these include[10] the deployment of maximum reservoir contact wells (MRC), intelligent autonomous fields, gigacell simulation, deep diagnostics (ability to see inside the reservoir with clarity), and advanced monitoring and surveillance technologies. These are just a fraction of available technologies that may help improve oil recovery and should be considered before full-scale deployment of EOR.

Another option to consider before EOR is 'smart water flooding'. Here, the idea is to inject water with an optimised composition (in terms of salinity and ionic composition) into the reservoir instead of any available water that may currently be injected or planned to be injected. Recent research has shown[11,12] that salinity and/or ionic composition can play a significant role in oil recovery during water flooding and may yield up to 10 per cent or higher additional oil recoveries when compared to unoptimised water injection. This option has several advantages compared to EOR:

• It can achieve higher ultimate oil recovery with minimal investment in current operations (this assumes that a water-flooding infrastructure is already in place). The advantage lies in avoiding extensive capital investment associated with conventional EOR methods, such as expenditure on new infrastructure and plants needed for injectants, new injection facilities, production and monitoring wells, changes in tubing and casing, for example.

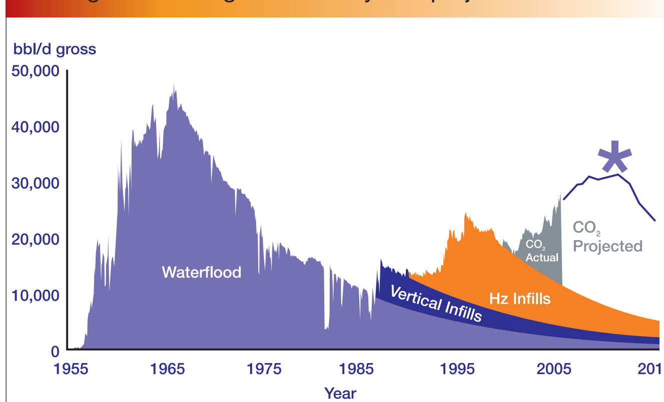
• It can be applied during the early life cycle of the reservoir, unlike EOR.

• The payback is faster, even with small incremental oil recovery.

Figure 9 shows the results from a BP study[11] of incremental oil recoveries (over and above water-flooding recoveries) in several sandstone reservoirs.

Smart water flooding is relatively new and in the technology development stage, however, the idea of customised water for improving oil recovery is very attractive. There have been a few field trials and pilots, mostly in sandstones, and fewer in carbonates. The initial results are promising and a number of questions remain, although R&D has been accelerating in

Figure 6: Timing of EOR: Weyburn project in Canada



this area. Saudi Aramco, through its upstream arm (EXPEC Advanced Research Centre), has initiated a strategic research programme in this area to explore the potential of increasing oil recovery by tuning the injected water properties.

Another aspect of water flooding that can be improved is the monitoring and surveillance (M&S) of projects. In many cases, adequate monitoring is not done because of the cost involved. This may, however, be detrimental to the overall recovery during water flooding. While an optimum M&S plan cannot be predetermined for a given reservoir, some of its components include: the time-tested open/cased hole logging, coring, flood-front monitoring, single and interwell tracer tests, and emerging technologies, such as: borehole gravimetry, crosswell and borehole to surface electromagnetic (EM), and geophysical methods (crosswell seismic, 4D seismic and 4D vertical seismic profiler (VSP)). A good M&S plan is essential in optimising oil recovery at the secondary recovery stage, and even more important during the EOR phase.

EOR enablers

Significant challenges still remain for the widespread deployment of EOR. Ultimately, however, companies will have to resort to EOR as the 'easy oil' gets depleted. This section discusses some of the EOR 'enablers'[5].

Focus on ultimate oil recovery

There is a concerted move around the world as companies (especially the national oil companies, and increasingly the international oil companies) realise that they need to focus on 'ultimate' oil recovery and not on 'immediate' oil recovery that is driven by short-term profits. This commitment to a long-term view will ensure the optimum exploitation of oil resources by keeping depletion rates low, improving secondary oil recovery through sustainable development and focusing on long-term profits. Appropriate EOR methods can then be deployed to maximise ultimate oil recovery.

Moving towards difficult resources

As the easy and conventional light oil gets depleted, a move towards more difficult hydrocarbon resources is already well under way. These resources include heavy and extra-heavy crudes, oil sands, bitumen and shale oil. Typically, the conventional oil recovery for these resources is generally low. An EOR method has to be implemented relatively early in these reservoirs. This has been, and will be, a primary driver for EOR, especially thermal, in the more difficult resources worldwide.

Life-cycle planning

A more holistic approach in the life-cycle planning of a reservoir is happening across the industry. The motivation towards maximising recovery, rather than thinking about short-term profits, helps in better resource exploitation. Life-cycle planning includes thinking about EOR early enough to conduct relevant R&D studies, feasibility testing and conducting pilots to enable key decisions to be made at the right time.

R&D

Investment in R&D is essential to generate the right options for field development. Often, in a drive to produce oil as fast as possible, incorrect strategy is adopted to develop an

Figure 7: IOR/EOR maturity and deployment

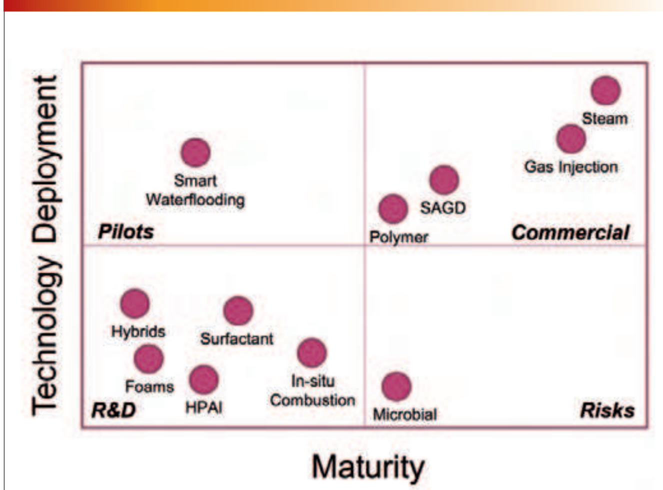
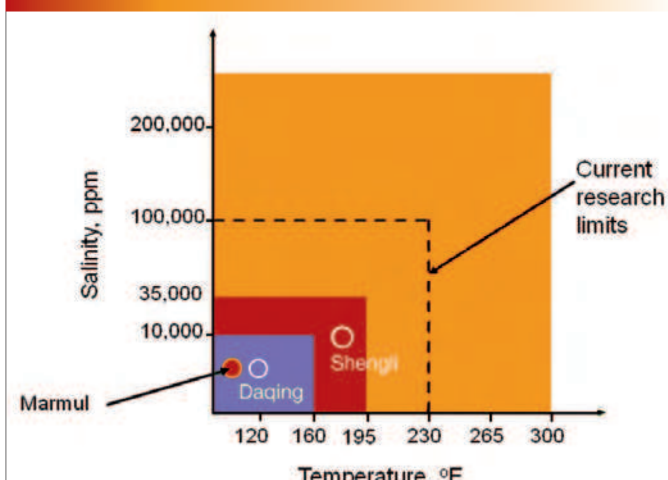
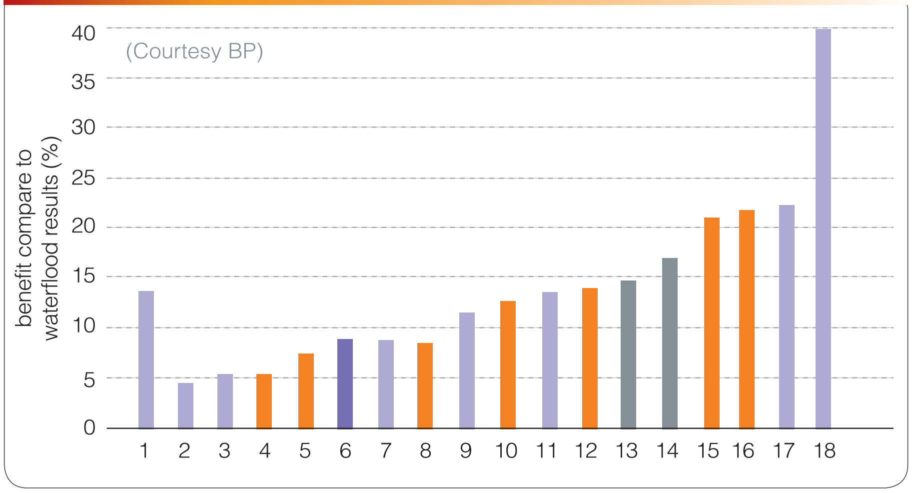


Figure 8: Chemical EOR challenges



oil reservoir. This can lower the overall recovery from the reservoir considerably. Proper R&D investment, especially early on, not only assures a good overall strategy for secondary recovery, but for EOR as well. A good example is the Marmul field in Oman where R&D studies and pilot testing with chemicals were done in the 1980s. This data and results helped PDO (Oman) and Shell to implement chemical EOR with little difficulty at a later date. Another good example is China, where R&D investment in chemical EOR has paid off handsomely with successful implementation of full-field EOR projects (two examples: Daqing and Shengli fields).

Figure 9: Summary of low salinity recovery benefits for various fields



Capability development

EOR projects are inherently complex compared to conventional recovery methods. These projects are also manpower-intensive, requiring highly-skilled professionals to run them. For companies that nurture, develop and possess these competencies, implementation of EOR will be easier. In addition, EOR professionals also ensure better IOR implementation strategies.

Stepwise implementation

EOR projects are also facilitated by stepwise implementation and integration of R&D, technology, people, and commitment. A stepwise implementation involves moving from laboratory scale tests, single well tests, pilot tests and on to full-field implementation. This will significantly reduce risks associated with typical EOR projects, and eventually improve overall economics.

Energy security

EOR implementation may be aided by a company's or country's need for energy security concerns. The US is a prime example of this need and has taken a true leadership role in EOR implementation in its fields, in spite of being a free economy. Another example is PDO where the dwindling oil production rates have forced it to implement EOR projects aggressively.

Environmental concerns

In recent years, a strong boost to EOR has come from environmental concerns. This is especially true for CO_2-EOR. CO_2, a greenhouse gas, has been closely linked to global climate change. There are incentives to sequester this CO_2. It is also a very good solvent for light crudes and is generally miscible with the oil at moderate reservoir pressures. The number of projects injecting CO_2 for EOR has been steadily rising and is anticipated to increase further in the foreseeable future. In many ways, this is a win-win situation, sequestering CO_2 at the same time as producing incremental oil. ❑

1. Stosur, G.J.: "EOR: Past, Present and What the Next 25 Years May Bring," SPE paper 84864, presented at the SPE IOR Conference in Asia Pacific, Kuala Lumpur, Malaysia, October 20-21, 2003.

2. Stosur, G.J., Hite, J.R. and Carnahan, N.F.: "The Alphabet Soup of IOR, EOR and AOR: Effective Communication Requires a Definition of Terms," SPE paper 84908, presented at the SPE International IOR Conference in Asia Pacific, Kuala Lumpur, Malaysia, October 20-21, 2003.

3. Moritis, G.: "CO_2, Miscible, Steam Dominate EOR Processes," Oil and Gas J., April 2010.

4. Thomas, S., "EOR – An Overview", Oil and Gas Science and Technology, Rev. IFP, Vol 63, #1, (2008).

5. Schulte, W.M.: "Challenges and Strategy for Increased Oil Recovery," IPTC paper 10146, presented at the IPTC, Doha, Qatar, November 21-23, 2005.

6. Manirique, E., Thomas, C., Ravikiran, R., et al.: "EOR: Current Status and Opportunities," SPE paper 130113, presented at the IOR Symposium, Tulsa, OK, April 26-28, 2010.

7. Wilkinson, J.R., Teletzke, G.F. and King, K.C.: "Opportunities and Challenges for EOR in the Middle East," SPE paper 101679, presented at the Abu Dhabi IPTC, Abu Dhabi, U.A.E., November 5-8, 2006.

8. Manrique, E.J., Muci, V.E. and Gurfinkel, M.E.: "EOR Field Experiences in Carbonate Reservoirs in the US," SPEREE, December 2007.

9. Awan, A.R., Teigland, R. and Kleppe, J.: "EOR Survey in the North Sea," SPE paper 99546, presented at the SPE IOR Symposium, Tulsa, OK, April 22-26, 2006.

10. Saggaf, M.: "A Vision for Future Upstream Technologies," JPT, March 2008.

11. Lager, A., Webb, K.J. and Black, J.J.: "Impact of Brine Chemistry on Oil Recovery," Paper A24, presented at the EAGE IOR Symposium, Cairo, Egypt, April 22-24, 2007.

12. Strand, S., Austad, T., Puntervold, T., Høgnesen, E.J., Olsen. M. and Barstad, S.M.: "Smart Water for Oil Recovery from Fractured Limestone: A Preliminary Study," Journal of Petroleum Science and Engineering, 2009.