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EOR: Past, Present and What the Next 25 Years May Bring

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Abstract

The paper presents an analysis of worldwide EOR activities and trends for the mid-term future. The focus of the paper is on EOR production levels and the corresponding number of projects within each major EOR technology group: thermal, gas flooding, chemical and other methods.

Most EOR activities are in North America where the conventional oil production decline is now well established and EOR is one of a few remaining options for additional oil production. In the United States, the unfavorable economic climate of the late 1980's caused the number of new EOR projects to decline rapidly, followed by the corresponding leveling of oil production and even a modest EOR production decline in 2002.

Thermal recovery continues to provide the largest, although it is declining fraction of EOR production. In the long-term, thermal recovery methods may play an increasingly important role in the recovery of the huge heavy oil and tar sands resources. Gas flooding continues to gain momentum and shows promise for further gains. Chemical flooding projects suffered from declining interest and negligible production rate. Fluid diversion via permeability modification control offers considerable near-term potential.

It is likely that EOR-produced oil in the United States has already reached its peak level and that it will increase above the current production rates only at substantially higher and stable oil prices. World's EOR production peak is likely to occur 30-35 years after the onset of global oil production decline, or in mid 2060's.

Definitions

There is much confusion around the usage of the term EOR and especially the term IOR. Ref. 1 describes the effort to reach agreement on the definitions to clarify communications by forming an industrial committee under the auspices of the SPE. This paper adheres to that proposed definition, Fig.1.

Enhanced oil recovery (EOR) refers to reservoir processes that recover oil not produced by secondary processes. Primary recovery uses the natural energy of the reservoir to produce oil or gas. Secondary recovery uses injectants to re-pressurize the reservoir and to displace oil to producers. Enhanced oil recovery processes target what's left. They focus on the rock/oil/injectant system and on the interplay of capillary and viscous forces.

EOR in Perspective

Just how did EOR evolve and what has been its share of oil production? In this regard it is helpful to note the current distribution of oil production by primary, secondary and tertiary (EOR), in the United States, which has remained without change for at least 15 years, Fig.2. Only 37 percent of oil produced in the United States comes from primary methods. Secondary methods of waterflooding and gas pressure maintenance contribute the lion's share of 51 percent. About 12 percent is produced by tertiary methods, also known as EOR.

Worldwide oil production by EOR is now 2.9 million barrels per day, or 3.7 percent of world's total oil production, Fig. 3.

Over the years, U.S oil production from EOR processes has grown steadily and reached a plateau from 1992-2000, Fig 4. The first significant EOR production decline occurred in 2002. Fig. 4 also illustrates several important trends with respect to the popularity of various EOR technologies in the U.S.:

- *Thermal projects*, mostly steamflooding, continue to contribute the largest fraction of EOR production, but growth rates stopped in 1988. In fact thermal EOR production has declined by 16 percent since 1998. Heavy oil production by steamflooding in California accounts for most of the decline.

- *Gas miscible and immiscible applications* enjoyed rapid rate of increase since 1982, but have leveled off since 1992, and even registered a small decline in 2002.

- *Chemical projects* exhibited a period of popularity from 1982 to1992, but never reached more than 4 percent of the total yearly EOR production rate. Since 1992, production rate from chemical flooding was negligible and only a very small fraction of one percent of total EOR production.

- *Microbial EOR*, despite over 100 field tests conducted worldwide, never achieved sufficient strength to allow a measurable production rate on par with other EOR methods.

Thermal recovery methods, even though their growth rate may have peaked in the United States, will continue growing elsewhere in the world, where massive heavy oil and tar sands are found and where environmental restrictions may not be as severe as those in the United States. As the world's conventional oil production starts to decline within 30 years, attention will be focused on the almost immeasurable quantities of heavy oil and tar sands, much of which can only be produced by thermal methods.

For the time being, gas injection methods continue to have the advantage over other EOR applications, particularly in the United States and Canada. The reasons are obvious, though different: there are a number of high quality, naturally occurring CO2 sources in the U.S., while Canada has an excess of natural gas which it successfully uses for miscible gas flooding.

Chemical methods in the U.S., despite two decades of heightened attention and publicity, were just never able to get off the ground. But, chemical flooding in China has been successful. Most operators shun chemical flooding, saying that it is too expensive and unpredictable.

The above conclusions should not be extrapolated indiscriminately, since too much depends on individual reservoir situations, availability of injectants, specific local conditions, oil prices, government incentives and many other factors beyond the control of operators.

Even more telling is the steady decline of the number of active EOR projects, Fig. 5. The number of active EOR projects has dropped steadily from 512 in 1986, to 147 in 2002, a decline of 71%. This may indicate that resources and technology are being applied by expanding ongoing promising projects rather than by starting new projects. Also, the better EOR projects demonstrated a positive cash flow, while new projects would not be profitable at expected oil prices. For whatever reason, companies are not now investing in new EOR projects at the rate they were through 1986 -- the year crude oil prices dropped to $12 per barrel. The outcome of the situation has led to an increasing amount of EOR production coming from a smaller number of projects. This is a "natural selection" process whereby the most effective and efficient processes continue to produce and flourish while those less efficient and effective are reduced or retained for additional technology development.

On one hand, the trend points to fewer EOR projects supplying an increasing amount of oil per project in a period of unpredictable and rapidly changing oil prices, attesting to the basic strength of the EOR technologies. On the other hand, the trend is less than encouraging for the future of EOR in the United States. While the 2002 dip in EOR production may have been spurious, the ten-year period of no-growth in EOR production, ending with a significant decline is sobering for the supporters of EOR technologies.

Several technologies that were believed to make large impact on EOR applications have not materialized. Technologies such as horizontal wells, 4-D seismic and crosswell tomography found only limited use. In the case of crosswell tomography, the cost is still relatively high compared to 3-D seismic surveys that provide information over a greater areal extent.

Traditional EOR methods have recently been challenged by rapid progress in exploration, including the 3-D seismic revolution accelerated by computer power. These achievements have called greater attention to discovery and development of smaller oil pools at the expense of EOR processes in maturing oil fields. Similar improvements in computational technologies and increased speed of data acquisition and processing are creating new opportunities for better reservoir management that is essential to successful EOR applications.

The Role of Technology

The decade of the 1990's marked extraordinary technological improvements in exploration, drilling, and production. The president of the American Petroleum Institute has stated "mind-boggling progress has cut the cost of finding and producing oil by 60 percent in real terms over the past 10 years."

According to the Energy Information Administration statistical reports, worldwide finding and development costs have declined from $21 per barrel in early 1980's to about $6 per barrel in late 1990's. Advances in exploration have caused oil discoveries per exploratory oil well completion to increase six-fold from the early 1980's to the late 1990's. In the upstream area relating to improved oil recovery, the cost-sensitive steam oil ratio has declined by a factor of two since the early 1980's. In general, however, it seems that the overall progress in EOR technologies during the 1990's did not keep pace with high-tech developments applicable to conventional recovery methods.

The 30th anniversary of the Offshore Technology Conference was marked with a display of technology that would have seemed like science fiction a decade earlier. Examples of innovative technologies include:

- Conversion of Star War defense laser technology to drilling. Two lab experiments resulted in equivalent rate of penetration of 166 and 450 ft/hr (2).

- Baker Hughes, Inc., revealed the concept of a "Downhole Factory," a production management system that combines fiber optics, robotics, artificial intelligence and other technology to convert natural gas into electric power within the wellbore. It has already formed alliances and trademarked the Downhole Factory title for the new technology that it expects to assemble within 10 years (3).

- Downhole separation of water that is produced with oil, a costly process at the surface because the water then must be reinjected, or otherwise disposed of, is already undergoing field tests (4).

- Cross-borehole seismic tomography, and the associated miniature (0.5 inch) geophone tools, that permit improved reservoir characterization on the interwell scale (5).

There is every reason to believe that technological advances will continue unabated. Even as we may eventually be running out of inexpensive, conventional oil, there are enormous resources of *unconventional* hydrocarbons that far exceed the conventional resources. The EOR knowledge and experience will be essential in commercial development of these resources.

What might the next 25 years bring?

An even more challenging question was posed for the panelists of the SPE International Conference on IOR in Kuala Lumpur, Malaysia, in 2001: Will *"50% of the World's Oil Production Come from IOR/EOR by 2020"*? Not surprisingly, there was no agreement, nor definitive answers.

Answering that question, even in a qualitative sense, is no less difficult than predicting today's desktop computing power 20 years ago. The outcome will, of course, depend on such variables as the rate of technology development, the world's economic activity, climate change scenarios, population growth, politics, oil price and its supply, and many others that are by themselves hard to predict.

Nonetheless, many economists and geoscientists have tried to look into the future of oil supply as far as the mid 21^{st} century, but none of the studies looked specifically into EOR contribution to the overall oil supply in the United States or the world.

Let us start with a few assumptions. First, assume that the definition of EOR is as proposed in Ref. 1, and shown on page 1 of this paper. The proposed definition of IOR from the same reference is: *Improved oil recovery (IOR) refers to any practice to increase oil recovery beyond primary production. That can include EOR processes as well as all secondary recovery processes, such as water flooding and gas pressure maintenance.*

Table 1 shows the percentage of oil produced by primary recovery, secondary recovery and enhanced oil recovery, for the United States and the world, for the period of 1970 to 2050.
The significance of the year 1970 is that the U.S. oil production reached its peak that year and started to decline from that time on. The significance of the year 2037 is that the world oil production will then reach its peak and will begin to decline (6). The following conclusions are drawn:

- In countries with long oil production history and a well established oil production decline, such as in the Unites States, EOR has seemingly reached a plateau and may not grow much more.

- EOR has always stayed at a level that is much below oil production by secondary methods, which also have reached ceiling and remained flat about 15 years ago.

- EOR is not likely to exceed oil production from secondary operations because waterflooding and gas pressure maintenance (secondary) will always be less expensive than EOR applications.

- For the foreseeable future, major oil companies will continue focusing on exploration for large reservoirs while pondering alternative energy sources and renewables. For them, it is simply a matter of survival. EOR is great, but has a limit to its growth, even at much improved oil prices.

- As in the United States, where EOR has leveled off about four decades after the country's onset of declining total oil production, the world's EOR will reach its peak about 30 years after the onset of its production decline, now thought to occur in

2037 (6). The EOR fraction of the world's total oil production would be similar to that in the United States.

- Within 25 years, economical and environmentally acceptable ways of oil production from the world's huge heavy oil and tar sands, as well as from other unconventional sources of liquid and gaseous hydrocarbons may be possible. Even before then, nuclear power is expected to provide much energy to many sectors of the economy, except the transportation sector. It is also conceivable that demand for oil (in particular) may be constrained, not so much by its supply, as by advancing developments in high efficiency automobiles or by concern for the environment.

The extreme sensitivity of EOR activity to oil price has been recognized and pointed out by the National Petroleum Council (NPC) study in 1984, (7). The study estimated EOR production levels at three price scenarios through the year 2010, Fig. 6. As early as 1984, NPC predicted that there would be little growth in EOR production at $20/bbl ("Implemented Case" scenario), and that EOR production would peak in mid 1990's. Considering that average oil prices during that time were closer to $20 than to $30/bbl, that projection has proved to be reasonably accurate, Fig. 6. However, the stated case was the most conservative of the many other scenarios and assumed no technological advances since 1984. The "Advanced Technology Case" suggested EOR production level at a rate nearly twice the level of "Implemented Case", which proved to be unrealistic. Overall, the study was overly optimistic.

Based on the documented history of EOR development and application in the U.S., EOR did not quite live up to its early promise. If the percentage of EOR as a fraction of total oil produced continues to increase, it is largely due to the declining total oil production in the U.S.

Table 1 shows actual and projected oil recovery in the U.S. and the world, by recovery type, for the period of 1970 to 2050. Currently, EOR contributes 12 percent of oil to the total oil stream in the U.S. This fraction may increase somewhat, if only because total oil production will continue to decline. It is unlikely that EOR contribution will exceed 18 percent of total oil production in the U.S. or elsewhere in the world. Substantially higher and more stable oil price levels are essential to reach over that threshold. And that is not in the cards any time soon.

Conclusions

It is likely that EOR-produced oil in the United States has already reached its peak level and that it will increase above the current production rates only at substantially higher and stable oil prices.

World's EOR production peak is likely to occur 30-35 years after the onset of global oil production decline, or in mid 2060's.

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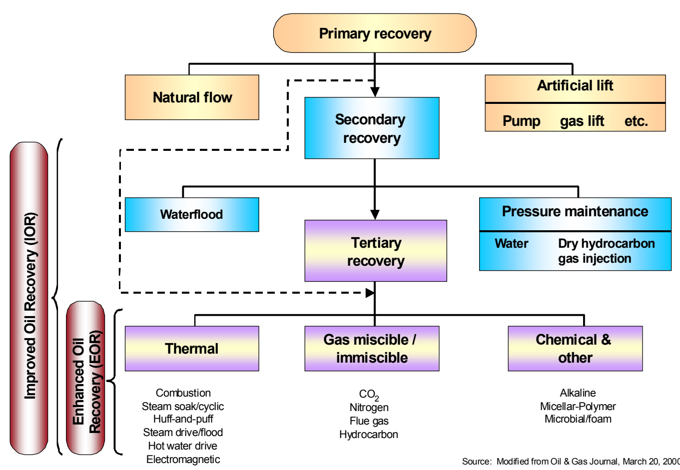

Fig 1. Sequential stages of oil recovery with proposed content for "Enhanced" and "Improved" oil recovery (modified after Oil and Gas Journal)

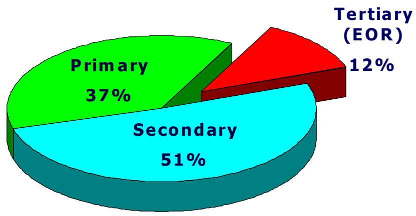

Fig.2. Sequential oil production cycles and their corresponding share in percent of contribution

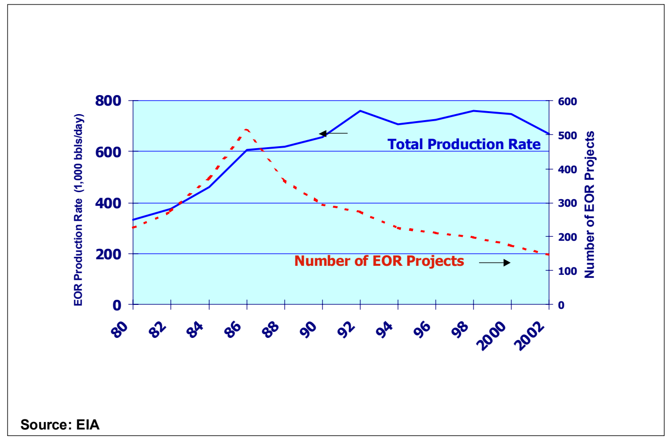

Fig.5. Correlation of U.S. active EOR projects and EOR production levels

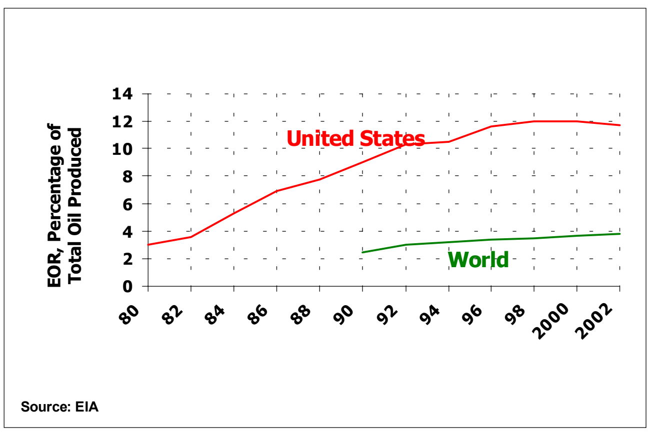

Fig.3. Historical growth of EOR in the United States and the world

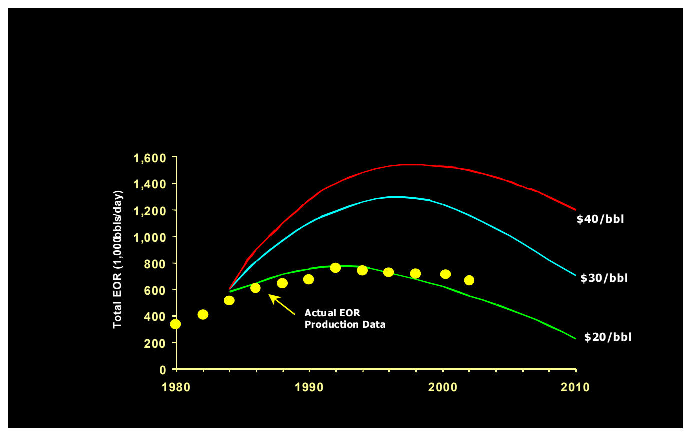

Fig. 6. Actual EOR production in the U.S. compared to the National Petroleum Council study, for three oil price scenarios. (Nominal crude oil price at constant 1983 dollars, implemented technology case, 10% min. ROR). NPC study on EOR.

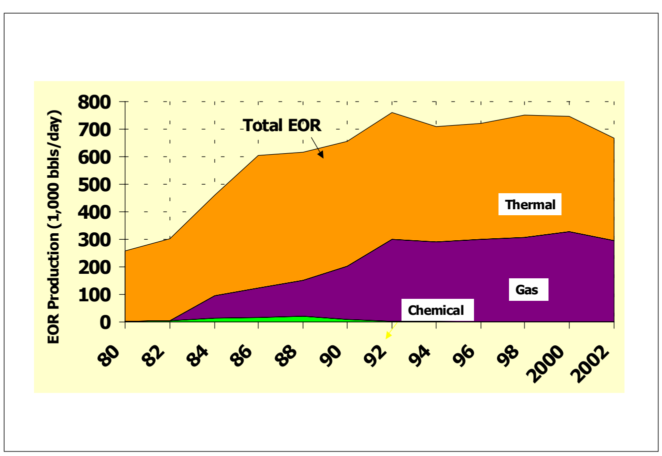

Fig. 4. EOR in the United States by major processes

	US Peak 1970 US	WORLD	2000 US	WORLD	2020 US	WORLD	World Peak, EIA 2037 US	WORLD	2050 US	WORLD
Primary	53	**n/a**	37	**56**	32	**48**	27	**43**	20	**35**
Secondary	45	**n/a**	51	**40**	54	**44**	57	**47**	62	**51**
Tertiary (EOR)	<2	**n/a**	12	**<4**	14 EIA	**8**	16	**10**	18	**14**

Table 1. Actual and projected oil recovery by processes for the U.S. and the world