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ENHANCED OIL RECOVERY IN LIBYA

E.O. Egbogah*, A.A. Misellati* and F.M. Krekshi*

تطبيقات وسائل الإسترداد الإضافي في الجماهيرية العظمى

د. إيجبوقا ، عزام المسلاتي وفؤاد الكريكشي

إستناداً على النتائج التي تم تحقيقها بحقل إنتصار، والذي يعد أحد أكبر الحقول الذي ينتج بوسائل الإسترداد الإضافي في العالم. بدأ خلال السنوات الأخيرة إعداد مخطط مشاريع الإسترداد الإضافي ، حيث تم إعتماده ، وبدأ العمل في إجراء الدراسات الفنية والتجارب المعملية لمجموعة من الحقول التي تم إختيارها بغرض الوصول إلى أحسن الطرق المناسبة للتطبيقات العملية وتحديد الجدوى الفنية والإقتصادية لهذه المشاريع.

تتناول هذه الدراسة إستعراض النتائج الأولية للمخطط وتناقش كميات النفط المتوقع إستخلاصها نتيجة لتطبيق وسائل الإسترداد الإضافي والمشاكل التي قد تعيق تطبيق المشاريع على جميع الحقول الليبية ، وتقترح وسائل معالجتها.

ABSTRACT

Building upon the experience of one of the world's largest hydrocarbon miscible projects at the Intisar "D" Reef, Libya is currently embarking upon what is undoubtedly the world's largest national program on enhanced oil recovery (EOR). Under the supervision of the National Oil Corporation (NOC), reservoir and process screening studies are in progress in many operating oil companies, and the results will identify appropriate EOR processes and the reservoirs to which they are amenable. These studies will also establish the technical and economic viability of the planned projects.

This paper discusses some of the preliminary results, and identifies, for the first time, the EOR target oil and the expected reserves therefrom. The technical and resource barriers to widescale application of EOR in Libya, are also dicussed and recommendations made for their remedies.

INTRODUCTION

On the average, Libyan oil reservoirs containing light oil, yield about one-third of the original oil-in-place, when produced using natural reservoir pressure (primary recovery) or by artificial injection of water or gas (secondary recovery). Currently available and emerging technologies, however, now provide the means to recover at least a further 10 to 20 per cent of the conventional oil remaining in many reservoirs. The recovery methods that are utilised to extract this oil are termed enhanced oil recovery (EOR).

There are two ways to increase crude oil reserves; discovery (exploration) and enhanced oil recovery. The preferred method of reserves additions appears to be clear. Exploration should be applied to new/young basins, such as the Murzuk and Ghadames, while EOR should be more applicable to highly explored, mature areas, such as in the Sirte basin. These seemingly clear decision path not withstanding, there are some obvious advantages of EOR over exploration. For example, exploration costs and risks which have been spiralling in the last two decades, are absent in EOR. In EOR we know where the billions of barrels of oil reserves are located. Exploration, on the other hand is highly probabilistic, and we do not know the location of the oil reserves, thus increasing the risk factor and consequent possible investment losses. Also, discoveries require sizeable new investments, while new EOR operations may utilise injection, production and transportation facilities that are for the most part, already in place. In the Jamahiriya, EOR is a proven method of oil reserves replacement; where Zueitina Oil Company operates one of the world's largest hydrocarbon miscible project at Intisar "D" Reef. Located in the Sirte basin of Libya, the Intisar EOR project produced at a

*National Oil Corporation, Tripoli, Libya, G.S.P.L.A.J.

peak rate of 155,000 STB/D in 1980 and currently produces 40,000 STB/D after 20 years of operation. The daily oil production from the Intisar 'D' Reef EOR project currently is equivalent to about 40% of all production from gas injection projects in the United States, and more than 80% of oil production from all EOR projects in Africa, Europe and Asia combined. Clearly, EOR is needed as a viable alternative to exploration.

Results of research on reserves and on exploration and production costs lead to the inescapable conclusion that petroleum will gradually be technically and economically more difficult to explore and produce. Both Simandoux [1] and Desprairies [2] conclude that for equal investments and efforts, EOR will yield significantly more conventional oil reserves than exploration in mature oil-producing basins. With these considerations in mind, the petroleum industry has focused considerable research and innovative development efforts on EOR objectives that appear to be essential in the present situation.

Enhanced oil recovery has the potential to increase the ultimate recoveries in Libya by about 20 billion barrels of conventional oil and extend the life of oil production by as long as fifty years, at current rate of production.

This paper discusses enhanced oil recovery in Libya in its multi-dimensional form, including current activities in research and development, project planning, design and implementation. The contribution of EOR in the national energy conservation, and social and economic well-being are also rationalised.

THE POTENTIAL OF EOR IN LIBYA

World-wide production statistics indicate that conventional primary and secondary recovery methods will produce only one of every three barrels of oil discovered to date. Of the remaining two-thirds, a portion is producible only through EOR technologies. Estimates indicate that the resources of oil in fields discovered to date in Libya, are about 130 billion barrels. The amount that can be recovered with current techniques is about 45.5 billion barrels (or 35%), out of which about 16 billion barrels have already been produced. Consequently, the oil that still has to be produced, (that is, the reserves of oil currently available in Libya's oilfields) is about 29.5 billion barrels (or 65% of the recoverable oil, otherwise known as reserves). At the current rate of constrained (OPEC) quota production, which is some 1.1 million barrels/day, these reserves correspond to about 73.5 years of production. For a more realistic reservoir management production rate of 1.5 million barrels per day, the life index of the remaining reserves of Libya will be 54 years.

The simple fact that emerges from the above figures is that the amount of oil left in the ground at the conclusion of current production operations is enormous. Taking only the fields discovered so far, we are talking about some 84.5 billion barrels of oil, which correspond to about 155 years of production and with a value, at current oil price of $18/bbl, of about 1520 billion dollars.

Some oil exploration experts believe that for every 5 barrels of oil already discovered to date throughout the world, some 3 more barrels are yet to be discovered in currently producing fields, as well as in such areas as the Deep Seas, the Arctic and the Amazon basin [3, 4]. This expectation can be extrapolated to the many largely unexplored basins of Libya. Thus, about 60% of the discovered 130 billion barrels of oil resources in Libya are yet to be discovered. These discoveries will lead to additional reserves of about 27 billion barrels producible by conventional techniques. This will also bring the quantity of oil in Libyan fields that represents the target for EOR technologies to about 135.5 billion barrels.

Data [5, 6, 7] indicate that in a carefully selected, well-designed, good-performing operation, an additional 30–50% of the original oil in place (OOIP, resource) can be recovered by EOR. Thus even if only 50% of the current EOR target oil in Libya were to be eventually produced, it would mean that the country has at its disposal, a further 13–21 billion barrels of oil reserves. This means that EOR clearly can constitute an important major alternative to future petroleum reserves supplies, and can serve as a solid reservoir management basis for a long-term projection of reserves availability. However, this potential is highly dependent on a broad spectrum of economic, technological and policy constraints, which require the concerted attention of both industry and national policy makers in order to realise and maximise the benefits of this resource for the people of Jamahiriya.

It is to be understood that the EOR target oil given in the foregoing sections, constitute a very gross estimate. No consideration has been given to the performance of individual major EOR technique. Considerable research and development work would be required to prove up the estimated reserves. Since many reservoirs may be suitable for the application of more than one technique, and because the economics of various techniques can change significantly with time, potential EOR reserves can readily shift from one EOR category to another. However, it is believed that such changes should not affect the total EOR potential. Thus, the total EOR potential given here are probably more meaningful than numbers on the potential of individual EOR technologies.

STAGES IN OIL RECOVERY OPERATIONS

Primary Oil Recovery:

Primary oil recovery relies on the natural reservoir energy to drive the oil through the complex pore network to producing wells. The driving energy may be derived from one or more of the following: gas that evolves from solution out of the oil; expansion of free gas; influx of natural water; or gravity force. Eventually, the natural drive energy is dissipated. When this happens, energy must be introduced into the reservoir to produce any additional oil.

Secondary Oil Recovery:

Secondary recovery involves the introduction of energy into a reservoir by injecting gas or water under pressure. Separate wells are usually used for injection and production. The added energy stimulates the movement of oil, providing additional recovery at increased rates. For clarity of reservoir engineering data and performance analysis, it is important here to outline the distinction between two secondary recovery processes involving water injection.

Water-pressure maintenance is a process whereby water is injected into the oil-water contact zone of an oil-producing reservoir to supplement the natural drive energy. A classical pressure maintenance by water injection (such as in the Parents field in France), is usually not intended to improve the recovery of oil, but rather, to increase the production rates, and thus accelerate the attainment of ultimate oil recovery. Waterflooding, on the other hand, is a secondary recovery method (such as in the BuAttifel field) in which water is injected directly into the oil leg, ostensibly to obtain additional oil recovery through an effective oil displacement and sweep of the reservoir. It is important to note that interfacial phenomena, in general, and wettability, in particular, are the controlling parameters in waterflooding.

The Remaining Oil:

Oil left at the conclusion of conventional recovery applications is retained in the pore spaces of the reservoir rock at a lower concentration than originally existed; the produced oil is replaced by gas and/or water in the pores. Rose [9] has given a detailed account of character and causes of residual oil in reservoirs, and here it suffices to say that residual oil is left macroscopically in the unswept parts of the reservoir and microscopically as droplets or ganglia in the pore network [10]. The forces which contribute to the retention of oil in the reservoir include restraining force of capillarity (blotter effect), gravity (buoyancy effect), and viscous forces (drag effect). These forces act simultaneously in the reservoir and the resultant effect depends on conditions at individual locations. The exact position of the oil depends on the nature of the reservoir topological and wettability attributes. Releasing the residual oil so that it can be produced is the sole intent of enhanced oil recovery.

WHAT IS ENHANCED OIL RECOVERY

The term "enhanced oil recovery" (EOR) refers, in the broadest sense, to any method used to recover more oil from a petroleum reservoir than would be obtained by primary recovery [5]. In primary recovery, naturally occurring forces, such as those associated with gas and liquid expansion or influx of water from aquifers, are utilised to produce oil. Conventional secondary recovery methods, such as waterfloods, are considered to be "enhanced recovery" methods under this broader definition. In this paper, we will consider EOR in a more narrow sense, and define it as the *additional oil recovery from a petroleum reservoir over that which can be economically recovered by conventional primary and secondary methods.*,

Innovative recovery technologies facilitate the extraction of oil previously inaccessible by conventional methods. These nonconventional methods, may include the introduction of extraneous energy (in the form of heat, miscible hydrocarbon fluids and carbon dioxide, or chemicals) into oil reservoirs to improve their recovery efficiency (See Fig. 1 for Oil Recovery Mechanisms). Kuuskraa [8] defines EOR as a collection of technologies, involving the use of thermal, gas, chemical means and horizontal drilling for producing more oil.

Other stand-alone methods of improving and/or sustaining oil recovery, such as infill drilling only, water injection and non-CO2 immiscible gas injection, should not be considered to be EOR per se. Nevertheless, infill drilling required for closer spaced EOR flood patterns, and water injection required to pressure up the reservoir for miscible gas injection processes, are only adjuncts to EOR. Also, immiscible gas (non-CO2) injection, if warranted for any reservoir's pressure maintenance purposes, or for gravity stable drives, should not be considered as EOR. These clear definitions are necessary for the proper credit of incremental oil recovery as well as more definitive project economics.

All enhanced oil recovery processes have several basic requirements in common:

A The process must mobilise oil which otherwise

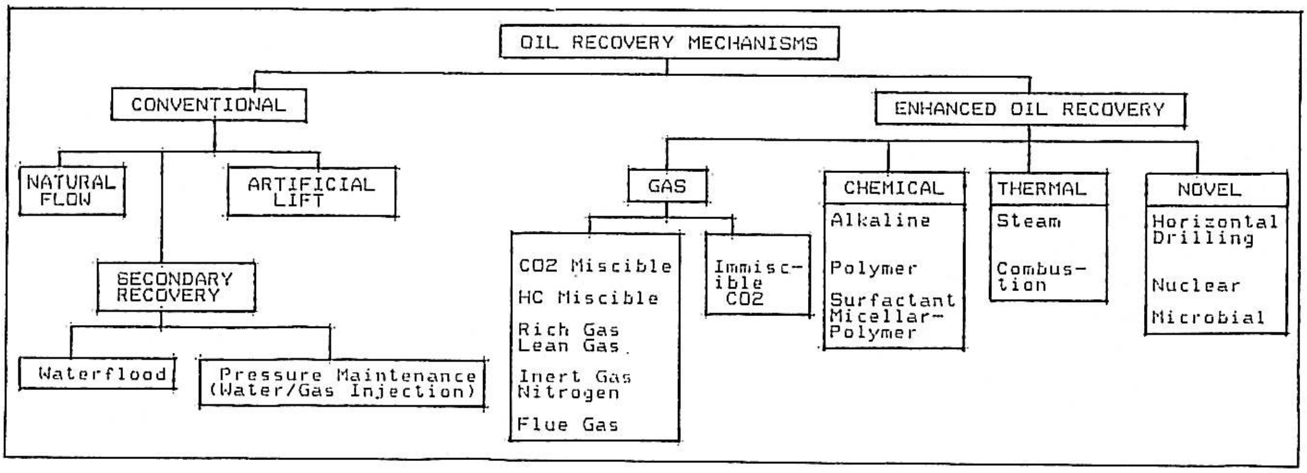

FIG. 1 Oil recovery mechanisms

would have been left unrecovered as residual oil. To mobilise such oil, the displacement efficiency must be improved.

B A substantially greater part of the reservoir must be contacted and swept by the injected fluid, that is, volumetric sweep efficiency must be improved.

C Any mobilised oil must be moved to the production wells and not retrapped in other parts of the reservoir, that is, the capture efficiency must be significant.

D Last, but not the least, the process must be economically viable.

Historically, EOR processes have been called "tertiary" processes in the sense that these were the "third" type of method to be implemented for the further development of the reservoir, and/or because it produces the "third" crop of oil. However, this has led to the severe misconception that these processes are to be applied only after the reservoir has been depleted completely by conventional "primary" and "secondary" methods. It is quite easy to see the fallacy of this conclusion. In a volumetric reservoir, no one will wait for a reservoir to produce all the oil that are producible by "primary" methods before introducing "secondary" recovery method of water injection. The terms "primary", "secondary" and "tertiary" are not to be misinterpreted to imply the time sequence in which these methods are to be implemented. They arise merely out of the chronology of their discovery by practising petroleum engineers, particularly in the United States. Unfortunate as it is, such misconceptions exist even today in the minds of some practising engineers, especially those specialising in conventional methods of petroleum development. In order to remove such misconceptions and obvious misnomer, these exotic processes were redesignated "Enhanced Oil Recovery Processes" to be consistent with our definition. We will stick to this nomenclature in this paper, and refer to all other processes such as "primary" or "secondary", as "conventional processes" to distinguish them from EOR processes.

WHEN SHOULD WE START EOR?

The timing of inauguration of enhanced oil recovery projects is critical. Experience has taught us that novel and more efficient recovery processes must be started in the reservoir as early as practically possible; not only to increase the production and ultimate recovery, but also to reduce the operating life of the field. This, no doubt, will give a more attractive rate of return on the operator's investment.

Conventional oil recovery operations in Libya fields are reaching mature status, and thus the reservoirs should be ideal candidates for EOR applications. And, most importantly, the current reserves additions through exploration do not replace production; that is, we now produce more oil than we find. In recognition of this fact, NOC is now embarking upon what may truly be described as the World's Largest EOR Program, and is working co-operatively with operating oil companies in conducting screening studies that will lead to both reservoir and process selection. Considering that at least ten years may be required to research various EOR processes, match them with reservoirs of their appropriate description, and develop the technical-economics viability criteria for the derivation of the project investment schedules, it is apparent that the time for concerted EOR action in Libya is now. The actions of NOC in this regard are therefore timely and praiseworthy.

WHAT PROCESS SHOULD WE CONSIDER?

Results of preliminary studies [11] indicate that many Libyan reservoirs lend themselves to the application of several EOR processes. No matter what process is to be applied, injectant availability, suitability and requirements must be considered early in the planning and design of an EOR project. Preliminary studies indicate that the techniques of chemical EOR are not cost-effective in Libya at the present time due to the logistics of importing disproportionately large volumes of chemicals, such as polymers, alkaline products, surfactants and co-surfactants. Microbial processes have limited database and therefore have not been considered in our screening program. Thermal processes have a possible application only in the Haram field, but has been eliminated from further consideration for other fields because the depth and pressures of these reservoirs make thermal processes economically unattractive for light oil reservoirs. Having eliminated chemical, microbial and thermal processes for now, technical and economics planning studies now focus on the assessment of gas injection processes for selected Libyan reservoirs.

The National Oil Corporation (NOC) has conducted preliminary studies on resource evaluation, allocation and utilisation of natural gases in Libya. The results reveal a critical insufficiency of suitably rich hydrocarbon resource base for EOR project implementation, thus compelling the investigation of alternative sources of other suitable gases for future planned EOR projects. This has led to the recent documentation of carbon dioxide resources and the prospects of their utilisation for EOR in Libyan oil reservoirs [12].

CONSTRAINTS ON EOR DEVELOPMENT

Constraints on EOR development include technical risks, material and human resource availability.

Technical Risks:

Complex technologies of EOR must be introduced and throughly mastered, and yet many of these are peripheral and emerging technologies which are alien to those who must practise them. This is particularly so in Libya with a limited EOR technological base.

While there is a large resource base to which certain EOR methods can be applied, enhanced oil recovery projects are difficult and costly, and the results do not become apparent until after most of the money has been invested. As a first step in examining potential development, reservoirs are screened to determine which projects might be technically feasible and what EOR processes might be appropriate. Specific candidates are then evaluated as to the amount of oil that will be left after primary and secondary recovery, and the particular charcteristics of the reservoir that will influence the amount of EOR oil. Because no two petroleum reservoirs are identical and the engineering data base is not completely until a pool is abandoned, there are many uncertainties in proceeding with reservoir development.

Technical risk arises from this complexity and uncertainty. Even though reservoir performance and recovery can now be estimated by computer modelling, the application of computer simulation and the process of scaling-up laboratory tests still result in large errors because of inadequate knowledge of the reservoir. Consequently, successful implementation of EOR schemes is by no means assured.

Technical constraints vary with each EOR process. For example, DOE/BETC [13] have indentified the major technical constraints to recovering more oil by gas injection operations. Because of our special interest in carbon dioxide flooding in Libya, we shall limit our discussions here to CO2. Carbon dioxide injection process is an example of a miscible displacement process that does not make use of the more expensive liquefied petroleum gases (LPG). However, the typical problems that need to be resolved for the successful application of this process include the following:

- The dynamic phase behaviour of CO2-oil-water systems is not sufficiently understood to be used for accurate prediction of reservoir performance.
- The type and nature of the displacement mechanisms, such as immiscible, single contact miscible, multiple contact miscible, for various reservoir conditions, are not yet fully understood.
- Mobility control is still inadequate.
- Problems of asphaltene precipitation, rock dissolution and deposition, and formation plugging, remain.

Because of the above, and other technical constraints, extensive laboratory research and field pilot testing of the desired EOR processes must necessarily be implemented. It is of course to be noted that planning, design, implementation and management of EOR pilots require considerable time and expertise which, in most cases, may not be available.

Economic Constraints:

Investment in EOR ventures depends on the investor believing that he will recover his investment in enhanced recovery within a reasonable period of time. The price of oil is only one of the factors influencing the investment decision. It is the netback, defined as the flow of revenue to the producer after deduction of all government taxes and royalties, which governs the inclination of the investor to proceed.

Royalty and tax regimes, in addition to prospective prices, can play a very important part in influencing decisions to undertake any high-risk investments. In EOR, because a return on operator's investment is realised after several years, a stable royalty, tax and pricing regime is essential. If the rules of the game are changed, a project that was economical when begun, could turn uneconomical before the incremental oil begins to flow. Thus changes in revenue sharing and in government regulations can either promote, or adversely affect EOR project starts.

Resource Constraints:

The need for research and development could be a determining factor in the rate of implementation of large-scale EOR projects in Libya. So far there is little or no evidence of R&D going on in Libya relating to EOR technology, and there is also no evidence of long-range basic research being conducted through the universities and the Petroleum Research Centre at a level commensurate with the country's EOR opportunities. Research and developoment, should therefore be launched at the said institutions. For the research to be relevant and timely, it must be carried out to take account of Libyan reservoir conditions. While certain EOR technologies are transferable, they may not always be appropriate. For example, some of the experience gained from many thin reservoirs of north America may not be transferable without adaptation to the very thick reservoirs of Libyan fields.

The most critical constraint, is skilled manpower. EOR projects require significantly more engineering expertise as well as geological reservoir description details than conventional oil recovery methods. EOR projects require multidisciplined group of experience engineers, researchers, geologists, and skilled field operators. To meet these stringent requirements, reservoir engineers and technicians require special training and experience in EOR methods. Research chemists and chemical engineers with training in petroleum processing are also required. Full-scale initiation of EOR projects in the magnitude envisaged by NOC will increase the demand for people trained in these areas, and thus will imply a need for a more substantial training effort of the local manpower.

CONCLUSIONS

Successful application of enhanced oil recovery technologies in selected producing Libyan fields can raise recoverable reserves from 35% to about 50% of the original oil in place. This is equivalent to an incremental oil recovery of about 20 billion barrels, which is nearly equal to the total remaining recoverable reserves from those fields by conventional methods.

The incremental reserves through EOR application may be considerably higher than the anticipted future exploration reserves. Efforts should therefore be devoted to the development of EOR reserves.

Enhanced oil recovery should serve as a solid basis for future reservoir management in Libya. It is a fossil energy conservation policy that will ultimately maximise the benefits of this non-renewable resource to the people. The social and economic consequences of this additional oil recovery are significant and strategic to the progressive development of the country, and could speed up the process of industrial transformation to products manufacturing technology base.

One of the most probable EOR techniques to be used in Libya is carbon dioxide injection. CO_2 flooding is a proven EOR process with broad application to reservoir rock and oil type. Because of its universal applicability and demonstrated success in many fields worldwide, and its abundance in Libya (in close proximity to many EOR candidate reservoirs), widescale utilisation of the process in Libyan reservoirs should be encouraged and investigated.

Major constraints to widescale application of EOR technologies to petroleum production in Libya exist; these include, technical, economic and resource availability. These constraints could be removed (or at least substantially reduced) through training, research and development.

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