EXTENT OF MEOR IN INDIA

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ABSTRACT

Recovering the residual oil that has been inaccessible in the depleted reservoir is the main force behind the extensive work done in the field of EOR (enhanced oil recovery). With the rapid decline in the discovery of oil reserves and increase in the oil consumption around the world, has been the reason for the need of new techniques in the EOR process for accessing the residual oil in the depleted reservoir. MEOR (Microbial enhanced oil recovery) is an EOR process that uses microbes and their bi-products to enhance the residual oil mobilization in depleted reservoir by modifying the properties of the oil and the interactions between oil, water and the porous media. MEOR research is picking up pace when compared to other EOR techniques as it doesn't depend on economic and technological limitations, i.e. it does not consume large amount of energy as do thermal process, nor do they depend on the price of oil as many chemical processes do. This process is cost-effective. This review provides an over view of types of microbes that are used in the role of enhanced oil recovery and the projects of MEOR done in India.

INTRODUCTION:

Nowadays the majority of the world's energy comes from crude oil. A large proportion of this valuable and non-renewable resource is left behind in the ground after the application of conventional oil extraction methods. Moreover, there is a dire need to produce more crude oil to meet the worldwide rising energy demand which illustrates the necessity of progressing Enhanced Oil Recovery (EOR) processes. These methods try to overcome the main obstacles in the way of efficient oil recovery such as the low permeability of some reservoirs, the high viscosity of the crude oil, and high oil-water interfacial tensions that may result in high capillary forces retaining the oil in the reservoir rock.

Microbial enhanced oil recovery (MEOR) is one of the EOR techniques where bacteria and their by-products are utilized for oil mobilization in a reservoir. In principle, MEOR is a process that increases oil recovery through inoculation of microorganisms in a reservoir, aiming that bacteria and their by-products cause some beneficial effects such as the formation of stable oil-water emulsions, mobilization of residual oil as a result of reduced interfacial tension, and diverting of injection fluids through upswept areas of the reservoir by clogging high permeable zones. Microbial technologies are becoming accepted worldwide as cost- effective and environmentally friendly approaches to improve oil production.

PRIMARY PRODUCTION:

Oil exists in the small pores and in the narrow fissures and interstices within the body of the reservoir rocks underneath the surface of the earth. The natural pressure of the reservoir causes the oil to flow up to the surface and provide the so-called primary production, which depends upon the internal energy and the characteristics of the reservoir rock and the properties of the hydrocarbon fluids. In some reservoirs, which are the parts of a much larger aquifer system, a natural flow of underground waters may be the drive force (aquifer drive) to push and displace oil. The initial reservoir pressure is usually high enough to lift the oil up to surface; however as oil production progresses, the reservoir pressure is continually depleted to a point in which artificial lift or pumping is required to maintain an economical oil production rate. In other reservoirs, there may be other recovery mechanisms, such as the expansion of dissolved gas during the pressure decline. As the reservoir pressure falls below the bubble point during production, some of the more volatile components are released and come out of solution to form small gas bubbles. Initially the bubbles are trapped in the pores and then their expansion causes oil displacement (dissolved gas drive). Furthermore in some reservoirs, as the pressure fall, gas bubbles increase in size and eventually coalesce forming a continuous gas phase that flows towards the upper part of the reservoir forming a gas cap. The gas cap constantly expands as the reservoir pressure continually decreases displacing more oil (gas cap drive) to the production wells.

SECONDARY PRODUCTION:

As the reservoir pressure declines during primary production, a critical point is reached when it is necessary to provide external energy for the reservoir to achieve additional oil recovery, which is termed secondary recovery. The extra energy can be introduced by injecting gas (gas injection) and/or water (water flooding).

Gas injection is usually only applied to reservoirs which have a gas cap where gas drive would be an efficient displacement mechanism. In Water flooding, which nowadays is one of the most common methods of oil recovery, keeps the reservoir pressure around the bubble point, thus preventing the pores to be blocked by dissolved gases. Also, according to the hydrocarbon thermodynamics, at the bubble point, the oil will have its lowest viscosity. So that, for a specific pressure gradient, the maximum amount of the oil will be displaced under this condition. After some years of operation in a field, due to the reservoir heterogeneity, the injected fluids (water or gas) flow preferentially along high permeable layers that cause these fluids to by-pass oil saturated areas in the reservoir. Therefore, an increasingly large quantity of water (or gas) rises with the oil, and by decreasing the ratio of oil to water, eventually it becomes uneconomic to continue the process and the field must be abandoned. In this situation, due to the low proportion of the oil production in both primary and secondary stages (about 30%), attention will be focused on the third stage of the oil recovery, so-called tertiary production or Enhanced Oil Recovery (EOR) for recovering more oil from the existing and abandoned oil fields.

TERTIARY PRODUCTION (or) ENHANCED OIL RECOVERY (EOR):

Generally, tertiary or enhanced oil recovery involves the extraction of residual oil after the primary and secondary phases of production. At this stage, modern and technically advanced methods are employed to either modify the properties of reservoir fluids or the reservoir rock characteristics, with the aim of gaining recovery efficiencies more than those obtained by conventional recovery methods (primary and secondary recovery stages). This can be achieved based on different mechanisms such as reducing the interfacial tension between oil and water, reducing oil viscosity (thermal methods), creating miscible displacement and increasing viscosity of the displacing fluid to be more viscous than the oil. The applied EOR method for each reservoir depends on its specifications, and requires a great deal of rocks and fluids sampling and also laboratory investigations. In general, EOR processes can be classified into four main categories as thermal methods, chemical methods, miscible or solvent injection, and microbial methods.

THERMAL PROCESS:

The general principle of thermal processes which are mostly used for recovery of heavy or viscous oils is to supply the reservoir with heat energy in order to increase the oil temperature and reduce its viscosity increasing the mobility of the oil towards production wells. Thermal processes can be conducted by two different methods: steam flooding and in-situ combustion. In steam flooding, steam at about 80% quality is injected into an oil reservoir, in which by condensing the steam, its heat energy transfers to reservoir rocks and fluids. This leads to the thermal expansion of the oil and the consequently reduction in its viscosity, and the release of dissolved gases. Steam flooding is the most widely used EOR method and probably the most profitable from an economic standpoint. In the in-situ combustion method (fire flood), which is theoretically more efficient than steam flood, burning some of the reservoir oil results in heating the reservoir and displacement of the remaining oil to the producing wells. But generally, due to the complex operational problems of this method, it is not widely applied.

CHEMICAL METHODS:

Chemical methods (chemical flooding) are claimed to have significant potential based on successful laboratory testing, but the results in field trials have not been encouraging. Furthermore, these methods are not yet profitable. In these processes, chemicals such as surfactants, alkaline solutions, and polymers are added to the displacing water in order to change the physicochemical properties of the water and the contacted oil making the displacement process more effective. In surfactant flooding, by reducing the interfacial tension between the oil and the displacing water and also the interfacial tension between the oil and the rock interfaces, residual oil can be displaced and recovered. Moreover, in caustic flooding, the reaction of the alkaline compounds with the organic acids in the oil forms insitu natural surfactants that lower the oil-water interfacial tension. In addition to surfactant and alkaline flooding, polymers are used to increase the viscosity of the displacing water to improve the oil swept efficiency.

MISCIBLE DISPLACMENT PROCESS:

The underlying principle behind miscible displacement processes is to reduce the interfacial tension between the displacing and displaced fluids to near zero that leads to the total miscibility of the solvent (gas) and the oil, forming a single homogeneous moving phase. The displacing fluid (injected solvent or gas) could be carbon dioxide, nitrogen, exhaust gases, hydrocarbon solvents, or even certain alcohols.

MICROBIAL PROCESS (MEOR):

Another tertiary method of oil recovery is microbial enhanced oil recovery, commonly known as MEOR, which nowadays is becoming an important and a rapidly developed tertiary production technology, which uses microorganisms or their metabolites to enhance the recovery of residual oil. In this method, nutrients and suitable bacteria, which can grow under the anaerobic reservoir conditions, are injected into the reservoir. The microbial metabolic products that include bio surfactants, biopolymers, acids, solvents, gases, and also enzymes modify the properties of the oil and the interactions between oil, water, and the porous media, which increase the mobility of the oil and consequently the recovery of oil especially from depleted and marginal reservoirs; thus extending the producing life of the wells (Lazar et al., 2007; Belyaev et al. 2004; Van et al. 2003). In MEOR process, different kinds of nutrients are injected to the reservoirs. In some processes, a fermentable carbohydrate including molasses is utilized as nutrient (Bass & Lappin-Scott, 1997). Some other reservoirs require inorganic nutrients as substrates for cellular growth or as alternative electron acceptors instead of oxygen. In another method, water containing a source of vitamins, phosphates, and electron acceptors such as nitrate, is injected into the reservoir, so that anaerobic bacteria can grow by using oil as the main carbon source (Sen, 2008). The microorganisms used in MEOR methods are mostly anaerobic extremophiles, including halophiles, barophiles, and thermophiles for their better adaptation to the oil reservoir conditions (Brown, 1992; Khire & Khan, 1994; Bryant & Lindsey, 1996; Tango & Islam, 2002). These bacteria are usually hydrocarbon-utilizing, non-pathogenic, and are naturally occurring in petroleum reservoirs (Almeida et al. 2004). In the past, the microbes selected for use, had to have a maximum growth rate at temperatures below 80ºC, however it is known that some microorganisms can actually grow at temperatures up to 121ºC (Kashefi & Lovley, 2003). Bacillus strains grown on glucose mineral salts medium are one of the most utilized bacteria in MEOR technologies, specifically when oil viscosity reduction is not the primary aim of the operation (Sen, 2008). History of MEOR

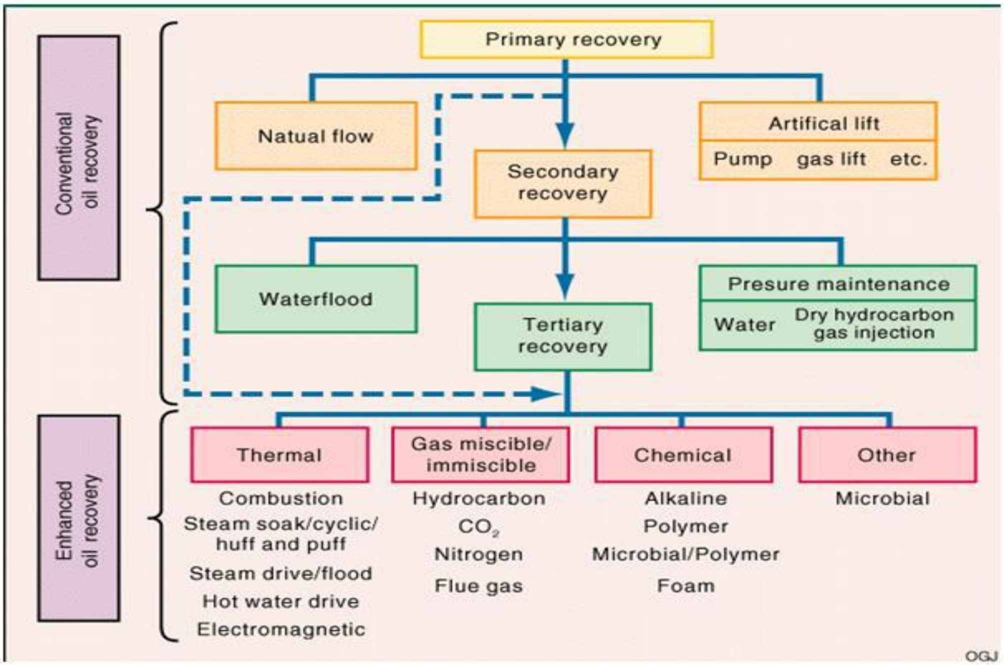
HISTORY OF MEOR:

MEOR was first described by Beckman in 1926. Few studies were conducted on this topic, between 1926 and 1940 (Lazar et al., 2007)[1]. In 1944, ZoBell patented a MEOR method and continued researching on this subject. In 1947, ZoBell initiated a new era of investigation in petroleum microbiology with applications for oil recovery. ZoBell explained that the major MEOR mechanisms which are responsible for oil release from porous media, involve processes such as dissolution of inorganic carbonates by bacterial metabolites; production of bacterial gases, which reduces the oil viscosity supporting its flow; production of surfaceactive substances or wetting agents, and the high affinity of bacteria for solids (Lazar et al., 2007). The first MEOR field test was conducted in the Lisbon field, Union County, AR, in 1954 (Yarbrough and Coty, 1983). The improvement of MEOR in field trials was based on the injection of mixed anaerobic or facultative anaerobic bacteria such as Clostridium, Bacillus, Pseudomonas, Arthrobacterium, Micrococcus, Peptococcus, and Mycobacterium among others; selected on their ability to generate high quantities of gases, acids, solvents, polymers, surfactants, and cell-biomass. More details on bacteria's specific abilities were reviewed by Lazar (Lazar, 1991, 1996 to 1998).

The application of MEOR as a tertiary recovery technique and a natural step to decrease residual oil saturation has been reported (Behesht et al. 2008). A complete review (692 references) of the microbiology of petroleum was published by Van Hamme et al. (2003), which covered a literature review up to 2002. This publication is mainly focused on the description of the molecular-biological characteristics of the aerobic and anaerobic hydrocarbon exploitation, with some citations on the application of the microbial action on petroleum waste, microbial oil recovery, and biosensors. The aspect of petroleum microbiology that is perhaps the most important for MEOR is the ability of microbes to use hydrocarbons as the carbon and energy source. Biotechnology research has improved, which has influenced the oil industry to be more open to the evaluation of microorganisms to enhance oil production. Both indigenous and injected microorganisms are used depending on their adaptability to the specific reservoirs. In microbial enhanced oil recovery (MEOR), bacteria are regularly used because they show several practical features (Nielsen et al., 2010). Several publications state that oil recovery through microbial action takes place due to several mechanisms as follows,

- Reduction of oil/water interfacial tension and modification of porous media wettability by surfactant production and bacterial action.
- Selective plugging of porous media by microorganisms and their metabolites.
- Oil viscosity reduction caused by gas solution in the oil due to bacterial gas production or degradation of long-chain saturated hydrocarbons.
- Production of acids that dissolve rock improving porous media permeability.

Particularly, the two first mechanisms are believed to have the greatest effect on improving oil recovery (Jenneman et al., 1984; Bryant et al., 1989; Chisholm et al., 1990; Sarkar et al., 1994; Desouky et al., 1996; Delshad et al., 2002; Feng et al., 2002; Gray et al., 2008; Nielsen et al., 2010).



MEOR MECHANISMS:

Improvement of oil recovery through microbial actions can be performed through several mechanisms such as reduction of oil-water interfacial tension and alteration of wettability by surfactant production and bacterial presence, selective plugging by microorganisms and their metabolites, oil viscosity reduction by gas production or degradation of long-chain saturated hydrocarbons, and production of acids which improves absolute permeability by dissolving minerals in the rock, however, the two first mechanisms are believed to have the greatest impact on oil recovery (Nielsen et al., 2010). So that, microorganisms can produce many of the same types of compounds that are used in conventional EOR processes to mobilize oil trapped in reservoirs and the only difference between EOR and some of the MEOR methods probably is the means by which the substances are introduced into the reservoir (Bryant & Lockhart, 2000). Table 1 summarizes different microbial consortia, their related metabolites and applications in MEOR

MICROBIAL BIOPRODUCTS: Microorganisms produce a variety of metabolites that are potentially useful for oil recovery [48]. There are six main bio-products or metabolites produced by microbes. Table 1 shows a summary of these bio-products and their application in oil recovery.

Product	Microorganism	Application in oil recovery
Biomass	Bacillus licheniformis, Leuconostoc mesenteroides, Xanthomonas campestris	MPPM, selective plugging, viscosity reduction, oil degradation, wettability alteration
Biosurfactants	Acinetobacter calcoaceticus, Arthrobacter paraffineus, Bacillus sp., Clostridium sp., Pseudomonas sp.	Emulsification, interfacial tension reduction, viscosity reduction
Biopolymers	Bacillus polymyxa, Brevibacterium viscogenes, Leuconostoc mesenteroides.	MPPM-Injectivity profile modification, mobility control, viscosity modification
Bio-solvents	Clostridium acetobutylicum, Clostridium pasteurianum, Zymomonas mobilis	Emulsification and viscosity reduction
Bio-acids	Clostridium sp., Enterobacter aerogenes	Increase in permeability, emulsification
Biogases	Clostridium sp., Enterobacter aerogenes, Methanobacterium sp	Increased pressure, oil swelling, interfacial tension reduction, viscosity reduction, permeability increase

MEOR ADVANTAGES:

The most outstanding advantages of MEOR over other EOR technologies are listed below (Lazar, 2007):

1. The injected bacteria and nutrient are inexpensive and easy to obtain and handle in the field.
2. MEOR processes are economically attractive for marginally producing oil fields and are suitable alternatives before the abandonment of marginal wells.
3. Microbial cell factories need little input of energy to produce the MEOR agents.
4. Compared to other EOR technologies, less modification of the existing field characteristics are required to implement the recovery process by MEOR technologies, which are more cost-effective to install and more easily applied.
5. Since the injected fluids are not petrochemicals, their costs are not dependent on the global crude oil price.
6. MEOR processes are particularly suited for carbonate oil reservoirs where some EOR technologies cannot be applied efficiently.
7. The effects of bacterial activity within the reservoir are improved by their growth with time, while in EOR technologies the effects of the additives tend to decrease with time and distance from the injection well

8. MEOR products are all biodegradable and will not be accumulated in the environment, therefore are environmentally compatible.
9. As the substances used in chemical EOR methods are petrochemicals obtained from petroleum feedstock after downstream processing, MEOR methods in comparison with conventional chemical EOR methods, in which finished commercial products are utilized for the recovery of raw materials, are more economically attractive.

MEOR DISADVANTAGES:

1. The oxygen deployed in aerobic MEOR can act as corrosive agent on non-resistant topside of equipment and down-hole piping along the reservoir.
2. Anaerobic MEOR requires large amounts of sugar that limits its applicability in offshore platforms due to logistical problems.
3. Exogenous microbes require facilities for their cultivation and experienced persons required for laboratory.
4. Indigenous microbes need a standardized framework for evaluating the microbial activity, e.g. specialized coring and sampling techniques,etc.
5. Microbial growth is favoured when: layer permeability is greater than 50 md; reservoir temperature is inferior to 80 ^{0}C, salinity is below 150 g/L and reservoir depth is less than 2400m.

MEOR PROJECTS DONE IN INDIA:

- Paraffin Degrading Bacterial (PDB) job in 45 wells at ONGC, Mehsana, Asset.
- Paraffin Degrading Bacterial (PDB) job in 30 wells at ONGC, Nazira, Assam
- 50 Wells at ONGC Ahmedabad Asset, Gujarat
- 09 Wells at ONGC Nazira Assam Asset
- 12 Wells at (Area-I) in ONGC Ankleshwar Asset, Gujarat

CONCLUSION:

According to the progress that has been achieved in implementing the MEOR technique in INDIA successful results have led us to the conclusion that MEOR is a better technique which can be implemented profitably. In spite of the cons of this technique like the requirement of professionals and it’s time consumption for the cultivation of bacteria, it proved itself with its significant oil extraction which is environment friendly and higher in recovery rates. Its cost effectiveness is being the eye-catching factor for the global oil industries. Research on this very technique is being carried out and its making a rapid progress.

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