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# The Futuristic Approach for Enhanced Oil Recovery, “MEOR”

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**Abstract:** Oil is generally found in the forms of ore in our earth crust. So, extraction of ore from earth crust employs various methods which generally include primary, secondary and tertiary methods. Microbial enhanced oil recovery is the tertiary oil recovery technique that employs the use of microbes and their by-products to enhance residual oil mobilization in the reservoir. The tertiary method also includes EOR (enhanced oil recovery) techniques in which physical and chemical methods are used. But sometimes it's not feasible to use EOR techniques as it is not suited economically, technologically and on environment stand point of view as it leaves the site with great amount of pollutant and that site cannot be further used in any other purposes. So, on those places and situation MEOR is the best technique to employ. It's just not an alternative technique but one of the best techniques emerging out as our understanding towards microorganism is increasing. It has great advantages against the tradition method's in which we use hazardous chemicals and dangerous steam for oil recovery. It has the potential to be one of the reliable technologies that suits the economic constraints of current oil market. The technology is a potential alternative to other EOR method as it is being implemented in most parts of the world with satisfactory results not only for economical point read however conjointly from having lesser environmental impact. Microbial process does not consume large amount of energy as thermal processes do, nor they are dependent on price of crude oil as many other chemical processes are and because microbial growth occurs as exponential rates, it should be possible to produce large number of useful products from inexpensive and renewable resources. These are some of the unique characters which make MEOR much more economically advance and much more profitable method for tertiary oil recovery method.

**Keywords:** MEOR (microbial enhanced oil recovery), ore, crude oil, microbial growth and EOR (enhanced oil recovery).

## I. INTRODUCTION

Crude oil is major source of energy in our present world. After the invention of conventional oil extraction method various oil methods and other sources of energy have been approximately diminished. Moreover, there is dire need to produce more crude oil to meet the worldwide rising demand which illustrate the need of progressing improvement in oil recovery method. These methods try to overcome the main obstacle in the way of efficient oil recovery such as low permeability of some reservoirs, the high viscosity of crude oil, and high oil water interface tension that may result in high capillary forces retaining the oil in the reservoir rock [1].

Microbial enhanced oil recovery is one of the microorganisms influenced oil recovery technique in which bacteria's and their biproducts are used for oil extract extraction from the reservoir. So, we can say that MEOR is the process in which we add active or extracted products of microorganism into the reservoir to expect an increase in the oil extracted from the reservoir by forming stable oil water mixture, flow of oil residues which is because of drop in interfacial tension and creation of alternative capillary through which oil can flow and can be extracted which were earlier being blocked by sand particles and other earthy materials. These techniques became renowned and people started accepting it because of various benefits which include cheap cost of extraction of oil and no harm is being created to nature [2].

Microbial Enhanced Oil Recovery (MEOR) is one of the technologies that can be potentially implemented with an exceptionally low operating cost: It has several advantages compared to conventional EOR processes as it does not consume large amounts of energy as do thermal processes, nor does it depend on the oil price as do many chemical processes. MEOR is simply the process of utilizing microorganisms and their bio-products to enhance the oil recovery. Bacteria are the only microorganisms used for MEOR by researchers due to their small size, their production of useful metabolic compounds such as gases, acids, solvents, bio-surfactants, biopolymers as well as their biomass. Also, their ability to tolerate harsh environments like those in the subsurface reservoirs in terms of pressure, temperature, pH and salinity increased their attraction to be used for EOR purposes. [3] The field trials have shown that normal projected oil production decline curve can be reversed or level off by MEOR and the reason is because microbial growth and metabolites produced can have effects on the chemical and physical properties of reservoir rocks and crude oil [4].

## II. HISTORY OF MEOR

MEOR was described firstly by Beckman in 1926 [5]. Not more studies were conducted in 20 years after Beckman but after 1947 zoobell started new age and advancement in petroleum extraction by microbes under program of petroleum microbiology. He directed various field experiment for extraction of petroleum and discovered various organism having ability to release oil from ore and sediments materials. Zoobell also described various mechanism by which microorganism acted on those ore or sediments some of them were secretion of organic acid and detergents by microbes, production of gases like CO<sub>2</sub> and dislodgement of oil by physical mean [6]. The first MEOR test was conducted in the Lisbon field, vision country, Arkansas in 1954 [7]. Various anaerobic bacteria like pseudomonas, clostridium, bacillus and many more were mixed with other microbes to improve the oil extraction. These anaerobic bacteria were added as they have addition property and improve the oil production in compare to the one without these anaerobic bacteria [8].

## III. STEPS OF PRODUCTION OF OIL

### A. Primary Production Of Oil

During early production of oil from reservoir, oil can pass through small capillaries which are created natural underneath the earth crust oil can also be extracted with the tiny pores below the earth surface. In initial stages of oil extraction, the pressure of oil is so high that no external pressure is needed for its extraction. This process of recovery of oil is called primary extraction of oil. This depend on various characteristics of the oil recovery site as well as the property of hydrocarbon fluid which is extracted.in some of the oil recovery sites which are located in oceans system, so the pressure generally depends on aquifer driven force which pushes and make oil move. During initial stages the pressure is high which helps the oil to come out naturally but as the process continues the pressure reduces and after a certain point in recovery of oil we need to apply external pressure with the help of pump which generated presses to keep oil flow continues to make the process economically feasible. There are some other method which can help o increase pressure there are addition of various dissolved gas. When the pressure of the oil reservoir falls below the pressure point which is called bubble point then that soil reservoir starts releasing various gases which comes out in the form of small bubbles. The gas bubble initially is entombed in small pores but gradually these bubble increase which start the formation of dissolved gas drive. If this process continues that the size of bubble constantly increases. As pressure falls this increases the gas cap drive making it more difficult to extract oil as the number of capillaries also increases which divert the path of oil extraction. [9]

### B. Secondary Production Of Oil

During the primary production of oil, the pressure of oil extracting site drops to a great extend and some external energy is required for the process to continue. There are two ways by which secondary oil production can be achieved those are by inserting gas (gas injection) or water (water flooding) into the oil extraction site. [9]

The reservoirs having gas caps are only preferable for applicability of gas for creation of external pressure. But water flooding is one of the preferred methods for extraction of oil because it keeps the pressure of the oil site near the bubble point which prevent the oil flowing capillary to be blocked by dissolved gases. According to hydrocarbon thermodynamics the oil has its lowest viscosity when it is near to its bubble point which help is flow swiftly without creating any blockage in capillaries. 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 [10].

### C. Tertiary Production

Tertiary production of oil is also known as enhanced oil recovery (EOR) which includes extraction of remaining oil from reservoir after primary and secondary oil extraction stages. In tertiary production of oil various advanced and latest methods are used which will change the property of oil or will modify the way oil extraction was done in primary and secondary method. Some of the most widely used method for enhanced oil recovery are reducing oil viscosity by use of thermal method, decreasing the interfacial tension between oil and water, addition of fluid which is more viscous than oil so that displacement velocity of oil increases. But Appling these methods widely depend of type of location the oil extraction site is situated and the availability of various sources for enhanced oil recovery. Various economical aspects are also taken care of. [9]



#### IV. DIFFERENT METHOD FOR EXTRACTION OF OIL IN TERTIARY PRODUCTION OF OIL

##### A. Thermal Processes

The basic principle behind this method is to increase the temperature of oil which is present at that extraction site. This method is generally used to extract heavy and viscous oil which is not itself capable to flow through pipes. Temperature is increased of that oil reservoir by supplying heat.

Heat can be transferred to oil in two ways water and in-situ combustion. In stream injection heated steam is passed to oil reservoir, this steam passes its 85% heat to oil and then condensation into water. This leads to decreasing of oils viscosity and thermal expansion of oil.

This leads to release of various dissolved gasses in oil and now this oil can easily can be recovered. This is one of the most common method for extraction of oil which is quite economic beneficial method. In in-situ combustion some of the reservoir oil is burned which result in elevated temperature of reservoir. This method is theoretically more beneficial than steam flooding, but this is actually very complex and dangerous method which is rarely practiced. [9]

##### B. Chemical Method

The success rate of chemical process in laboratory are quite high which makes these methods quite promising, but field trial is not encouraged due to various problems. Additionally, this method is quite expensive in compared to other method which makes them non-selectable on economical point of view.

In this method various chemical such as surfactants, alkaline solutions, and polymers are added which alter the property of physiological water making the oil displacement.

Surfactant flooding decreases the interfacial tension between capillary of extraction oil and oil so that oil can be recovered easily. Additionally, in caustic flooding in which oil and alkali react with each other in form in-situ natural surfactant that decreases water-oil interfacial tension. To increase viscosity for displacement of oil addition of surfactants and alkaline flooding to improve oil extraction. [9]

##### C. Miscible Displacement Processes

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. [9]

##### D. Microbial Enhances Oil Recovery (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 [11]. It is very important to get appropriate bacteria which can grow in anaerobic condition and utilize the nutrients which we provide them and grow in reservoir condition. Various microbial products like biosurfactants, solvents, organic acid and other metabolic product which includes enzymes which can alter the property of oil and interact with oil, water, and the porous media which makes oil possible to come out of the well easily and can be collected from reservoir and thus increasing the quantity of oil which is been extracted from reservoir [12].

For proper function of microbe's appropriate nutrients are very important and these nutrients are injected in the reservoir. These includes fermentable carbohydrates like molasses is used as nutrient by those bacteria [13]. Inorganic source of nutrient is required by some of the microbes for their growth or as electron acceptor in place of oxygen.

An alternative method can also be used in which water contain all vitamin, phosphate, and electron acceptor such as nitrate, is injected in reservoir so that anaerobic bacteria can utilize carbon sources which are available and grow on oil considering it as main energy source [14].

Halophiles, thermophiles and basophiles are main anaerobic microbes which are used in this process, these organisms are mainly anaerobic organisms [15]. These bacteria are generally present in oil fields, non-pathogenic and utilize hydrocarbons for their need of energy [16]. The minimum requirement for these types of organism is that they should grow at 80°C but now even microbes which can grow on 121°C are even available [17]. As glucose, mineral salts medium is generally utilized by bacillus strain bacteria in MEOR technologies, specifically primary aim is to reduce the viscosity of the oil under use [15].

## V. SELECTION OF MICROBES FOR MEOR

We can differentiate microorganism according to their oxygen intake and thus can be divided into 3 brief categories: the organism which can't even tolerate even minute quantity of oxygen known as strict anaerobes, the organism which requires oxygen for their growth known as aerobes and the organism which can tolerate minute quantity of oxygen and grow known as facultative anaerobes. These anaerobic bacteria do not contain enzymes which are required for utilization of the oxygen [18]. Anaerobic bacteria show highest success rates in MEOR [19]. There are many sources from which bacterial species that are MEOR candidate can be isolated. Lazar explained four main sources that are suitable for bacterial isolation [20]. Water purification plants have sediments from where we can isolate such kind of microbes. They can also be obtained from sludge of biogas plant and effluent of sugar industry as contain high amount of carbon and minerals and contribute about 30% of the total cost of the manufacture setting [21]. There are generally 3 major requirements of microbes for growth which are carbon, nitrogen and phosphate which are in the ratio of 89:10:1. Optimization of this nutrient is very much important for the maximum growth and oil recovery from the microbes [3].

## VI. MEOR MECHANISM

There are various mechanism in which we use microbes to increase the oil extraction mechanism of those microbes and apply these mechanism to the oil production site, some of the mechanism are changing of wettability by using surfactants another is decreasing of water interfacial tension (ITF), by presence of microbes like bacteria for selective plugging and by using their metabolic products, decrease in oil viscosity, digestion of long chain saturated hydrocarbons [22]. There are six main bio-products/metabolites, produced by microbes. The table below shows a summary of these bio-products and their application in oil recovery [22].

### A. Bio-Surfactants

They are the molecules having both hydrophobic region as well as hydrophilic part thus amphoteric in nature and thus are primary metabolite of many microorganism. They generally increase the solubility of components in oil field which results in improvement of oil mobility and of hydrophobic compounds, the mechanism which is applied here is reduction of surface as well as interfacial tension bio surfactants maintain their activity under high PH, temperature and salt concentration which make them quite effective as their chemical properties are not altered and thus are high value substances [23].

### B. Biomass

The growth rate of bacteria is quite high and multiplying then in approximately 20 mins and in no time their counts are in millions under aerobic condition [18]. In this method of tertiary enhanced oil recovery step bacteria are allowed to grow on permissive region which block the extra capillary though which oil can escape and thus maintaining oil quantity and pressure. This forces the extra water in the extraction well to divert its direction and can prove effective when only small quantity of oil is present in the well [24]

### C. Bio Solvents

Microbes produce some of the bio solvents as a part of their metabolism, some of the bio solvents produce by microbes are ethanol, acetic acid, butanol which are produce in initial growth phase of microbes in process of fermentation. Anaerobic bacteria in their stationary phase produce chloride as secondary metabolite which can act as great bio solvent for extraction of oil by decreasing the oil viscosity and can also be added as a surfactant to reduce interfacial tension between water molecules and oil present in reservoir [25]

### D. Bio Polymers

Bacteria produce various compounds like polysaccharide to protect themselves from predator and surviving in adverse condition between the competitive environment [26] and [15]. This method allows the addition and action of those polymers to the selective zone redirecting the water flow in one particular direction where the oil is concentrated [26].

Another important mechanism this polymers play is by controlling the viscosity, thus controlling mobility of water and hence maintaining the ration of mobility to sweep efficiency [27].

### E. Bio Acids

Lactic acid, butyric acid, acetic acid are some of the acid which are secreted by some of the microbes under certain condition [28]. These acids can be useful in carbonate reservoirs or a sandstone formation sandwiched by carbonates, since some of these cause dissolution of the carbonate rock and hence improve its porosity and permeability [29]. Anaerobic sugar formation can be done by bacteria in the normal phase of their growth. For example, clostridium sp are capable of producing 0.0034 mole of acid per kg of molasses [30].

#### F. Bio Gasses

Carbon dioxide, hydrogen and methane are the gasses which can be produced by microbes in the process while fermenting carbohydrates. These gasses can be utilized to increase pressures in oil well and in enhancing oil recovery process. These gasses can also help in decreasing the viscosity of the oil. This can be very useful in pressure decreased condition in reservoir. [15]. These gasses also have capacity to dissolve in oil and thus reducing the viscosity of the oil [29]. Some of the reported gas-producing bacteria are Clostridium, Desulfovibrio, Pseudomonas and certain methanogens [31]. Methanogens produce about 60% methane and 40% carbon dioxide where the methane will partition between oil and gas phase while carbon dioxide will partition to the water phase as well and hence improve the mobility of oil [3].

### VII. MEOR FIELD TRIAL

MEOR studies were originally developed for laboratory studies [32]. There are two main purposes to go for MEOR field applications, as single well treatment and full field treatment. Single well treatment includes well stimulation, wellbore clean-up and others. In this treatment process, improvement in oil production can result from removal of paraffinic or asphaltic deposits from the near wellbore region or from mobilization of residual oil in the limited volume of the reservoirs that is treated [11].

MEOR process variables must be optimized before it develops into a practical method for common field trials or application. These variables include a better description of the candidate reservoirs, better knowledge of the biochemical and physiological characteristics of the microbial consortia, a better handling of the controlling mechanisms, and an unambiguous estimation of the process economics. Most of the MEOR processes leading to field trial have been completed in the last two decades and now the knowledge has advanced from a laboratory-based assessment of microbial processes to field applications globally [32] [33].

As the treatment of MEOR really varies case to case and situation to situation so it is very important to study some of the world wide renowned MEOR cases and knowing the impact they created in tertiary oil recovery method. So here we are taking in consideration two of the MEOR successfully treated sites which act as a benchmark for utilizing microbes as tertiary oil recovery method.

#### A. San Andrews Project

The San Andrews reservoir was discovered in 1945 and was produced by solution gas drive until 1967 when water flooding was started. The original oil in place was 355 bbl/acre-ft, at 70% oil saturation. When MEOR technique was employed in the October of 1994, oil in place was 239 bbl/acre-ft with an oil saturation of 41%. Rock properties are relatively inhospitable for microbes. The low 1.7 md average horizontal permeability would normally be indicative of pore throat size well below what microbes could enter. However most of the oil is produced from natural fractures which the microbes can penetrate. Reservoir temperature at 115°F is ideal for microbe growth. [3]

- 1) *Treatment*: The treatment consisted of ten barrels of microbe laden water down the annulus. On the initial treatment the wells were shut-in for three days. Subsequently, they have been shut-in overnight. For the first three months the wells were treated every 14 days, thereafter approximately every 28 days. [3]
- 2) *Evaluation*: The reservoir was stabilized on a consistent 6.5% per year decline for three years before MEOR was begun. The decline was flattened to 0.6% per year. Water production on this property is blended with fresh water and injected. Produced water is measured only by well tests and is not accurate enough to draw a conclusion regarding reduction in water cut. Over a period of 19 months 17,000 barrels of incremental oil have been produced which is seven percent (7%) over the baseline. Current oil production of 440 barrels per day is 10% over the baseline. The incremental increase is expected to reach 15% by the end of the project life. At the end of its life, the water flood would have lifted oil in place 205 bbl/acre-ft versus 199 bbl/acre-ft with MEOR. Residual oil saturation is projected to decrease from 35% under water flood to 34.1% with MEOR. [3]

#### B. Queen Sand Project

This reservoir was discovered in 1984 and was quickly water flooded due to its very low solution gas content. Injection was beginning in 1990 and oil production increased quickly from 200 to 2,500 barrels per day. This rate continued until late 1991 when a rapid decline began. At the start of MEOR in August of 1992, oil in place was 728 bbl/acre-ft with an oil saturation of 56%.

Rock properties are generally favourable for microbe colonization. Average permeability is 13 md with an upper limit of 300 md and provides adequate pore throat size for microbes to colonize. Additional permeability developed by fracture treatment with 60,000 gallons and 135,000 pounds of sand on initial completion provided excellent porous media for microbe colonization. Reservoir temperature at 110°F is ideal for microbe growth. Average production per well is 42 BOPD at 74% water cut. The wells are rod pumped with low producing fluid levels. The formation contains salt and anhydrite and formation water is saturated brine. [3]

- 1) *Treatment*: Over the first nine months of MEOR treatments 11 of the 18 wells were treated with 400 to 450 barrels of microbe-laden water squeezed down the annulus followed by a 3-day shut-in. Three more similar squeezes were performed later. Routine batch treating was later begun in September of 1992. The wells were treated weekly with 32 barrels of microbe-laden water followed by a 6-12 hours shut-in. In late 1994, the frequency was reduced to every 14 days. Then in early 1995, the frequency was increased only on selected wells back to every 7 days [3].
- 2) *Evaluation*: The reservoir was on a 39% per year decline for 10 months before MEOR was begun. The decline flattened for several months, and then resumed at 31% per year. In late 1994, the injection pattern was altered by the conversion of two wells from producers to injectors and the injection rate has increased. Although the benefits of MEOR continue, comparison to the original baseline was inaccurate. Water production continued to increase after the start of MEOR. The rate of increase in water-cut decreased from 24% per million barrels to 12%. Over the first 24 months 240,000 barrels of incremental oil was produced which is 34% over the baseline. Oil production at the time the injection pattern was changed was 1000 bbls/day, 43% over baseline. The cumulative incremental increase was projected to be 47% by the end of the project life. At the end of its life, the water flood before the pattern changes would have left oil in place 691 bbls/acre-ft versus 660 bbls/acre-ft with MEOR. Residual oil saturation was projected to decrease from 51.4% under water flood to 49.1% with MEOR [3].

### VIII. CONCLUSION

MEOR is one of the best and proven techniques for tertiary enhanced oil recovery process and it has proven the same by successful application in various oil wells and various oil extraction sites. MEOR is eco-friendly as well as economical process which is the great advantage of this method over old EOR method. Despite of all these advantages and all this plus against the old EOR method MEOR has gained very less credibility because it is based on field trials. Most of the work done on MEOR is generally done in laboratory and shortage of field trial is clearly seen, as this method is based on field trial more field trials are required to prove its efficiency. Beside all current advantages we if see long term effect on Applying this method they are huge. Although MEOR is best technique sometimes it misses the engineering design criteria required for application of method in field. So being one of the best tertiary oil recovery method field trials are required and this will prove itself as one of the earth and money preserving technique.

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