Examining enhanced oil recovery (eor) techniques

Enhanced Oil Recovery (EOR) is a generic term for techniques used for increasing the amount of crude oil that can be extracted from an oil well. Using EOR, 30-60 % of the reservoir original oil can be extracted compared with 20-40% using primary and secondary recovery techniques.

Enhanced oil recovery is also called improved oil recovery or tertiary recovery. This improved extraction is achieved by gas injection, chemical injection and thermal recovery (which includes cyclic stream, stream flooding, and fire flooding). Gas injection is the most commonly used EOR technique; here gas such as carbon dioxide (CO_2), natural gas, or nitrogen is injected into the reservoir whereupon it expands and thereby pushes additional oil to a production wellbore, and moreover dissolves in the oil to lower its viscosity and improve the flow rate of the oil. Oil displacement by carbon dioxide injection relies on the phase behaviour of carbon dioxide and crude oil mixture that are strongly dependent on reservoir temperature, pressure and crude oil composition. These mechanisms range from oil swelling and viscosity reduction for injection of immiscible fluids (at low pressure) to completely miscible displacement in high pressure applications. In these applications, more than half and up to two-third of the injected carbon dioxide returns with the produced oil and is usually re-injected into the reservoir to minimize operating cost. The remainder is trapped in the oil reservoir by various means.

Other techniques include thermal recovery (which uses heat to improve flow rate) and, more rarely, chemical injection, where polymers are injected to increase the effectiveness of water floods or the use of detergent-like surfactants such as to help lower the capillary pressure that often prevents oil droplets from moving through a reservoir. Surfactant enhanced water floods are used for oil recovery where surfactants are injected with polymer.

Microbial Enhanced oil Recovery (MEOR) is particularly suited for application in carbonate reservoir, after secondary oil recovery, there are still large amount of oil left in the reservoir. Some bacteria are able to increase the oil production when injected into the oil reservoir. To stimulate such anaerobic microbial increased oil recovery, nutrients is injected together with the injection water.

Oil recovery requires two to three stages which are briefly described below

- Stage 1: Primary Recovery – 12 – 15 % of the oil in the well is recovered without the need to introduce other substances into the well.
- Stage 2: Secondary Recovery – The oil well is flooded with water or other substances to obtain an additional 15-20% more oil from the well.
- Stage 3: Tertiary Recovery – This stage may be accomplished through several methods which includes MEOR to additionally recover up to 11% more oil from the well.

Layout for different recovery techniques are shown in figure 1. Primary and secondary recovery techniques are usually called conventional recovery. Primary recovery is done by natural flow which is usually enhanced by reservoir natural pressure, and artificial lift such as pumps and gas lift, etc. Secondary recovery is done by water folding and pressure maintenance by gas reinjection. Tertiary recovery techniques cover broad area which includes thermal recovery such as in-situ combustion and steam flooding, solvent recovery is done by methods such as polymer flooding and surfactant enhanced water flood. Chemical enhanced recovery methods include gas injection or hydrocarbon miscible injection and nitrogen and flue gas flooding. Microbial enhanced oil recovery which is the main focus of this project will be explained better in the next chapter, but it is basically injection of microbes such as bacteria into oil reservoir to help recover oil. All these methods of oil recovery will be explained briefly.

PRIMARY RECOVERY

If the underground pressure in the oil reservoir is sufficient, then this pressure will force the oil out to the surface of the earth. Gaseous fuel, natural gas or water is usually present, which also supply needed underground pressure. In this situation, it is sufficient to place a complex arrangement of valves (Christmas tree) on the well head to connect the well to a pipeline network for storage and processing. Normally oil is recovered by natural means and artificial lift like pumps and gas lift.

SECONDARY RECOVERY

Over a lifetime of an oil well, the pressure will fall and at some point there will be insufficient underground pressure to force the oil to the surface of the earth. If economical, as often is, more oil in the well is extracted using secondary recovery methods. Secondary oil recovery uses various techniques to aid in recovering oil from depleted or low pressure reservoir. Sometimes, pumps such as beam pumps and electric submersible pumps (ESPs) are used to pump the oil to the surface of the earth. Other secondary recovery techniques increases the reservoir’s pressure by water injection, natural gas reinjection and gas lift, which inject air, carbon dioxide or some other gases into the reservoir. Together, primary and secondary recovery generally allows 25-35 % of the reservoir oil to be recovered.

Water injection

The productivity of existing oil wells can be significantly increased by the use of water injection. Statistics has shown that a reservoir produces just 37% oil in the first recovery. By using water injection, a reservoir can produce more than 50% of its oil. One of the most important issues during oil production is to keep the matrix/formation as clean as possible to maintain maximum oil production. Water is injected for two reasons: first is for pressure support of the reservoir. Second is to sweep or displace the oil from the reservoir, and push it outward.

Gas lift

Gas lift is one of a number of processes used to artificially lift oil from a well, where there is insufficient reservoir pressure. The process involves injecting gas through the tube-casing annulus. Injected gases aerate the fluid and reduce its density so the formation pressure is then able to lift the oil column and forces the fluid out of the wellbore. Gas may be injected continuously or intermittently, depending on the producing characteristics of the well and the arrangement of the gas-lift equipment. Although the gas is recovered from the oil at a latter separation stage, the process requires energy to drive a compressor in order to raise the pressure of the gas to a level where it can be reinjected.

TERTIARY RECOVERY

Tertiary recovery reduces the oil viscosity to increase oil production. Thermally enhanced oil recovery methods (TEOR) are tertiary recovery techniques that heat the oil and make it easier to flow or extract. Steam injection is the most common form of TEOR, and is often done with a cogeneration plant. In this type of cogeneration plant, a gas turbine is used to generate electricity and the waste heat is used to produce steam, which is then injected into the reservoir. In-situ burning is another form of TEOR, but instead of steam, some of the oil is burnt to heat the surrounding oil. Occasionally, detergents are also used to decrease oil viscosity as a tertiary oil recovery method, another method to reduce viscosity is carbon dioxide flooding. Tertiary recovery begins when secondary oil recovery isn't enough to continue adequate production, but only when the oil can still be extracted profitably. (Hitzman 1983)

Gas injection or Hydrocarbon Miscible injection

Gas injection is the most commonly used EOR technique, here, gas such as carbon dioxide is injected into the reservoir whereupon it expands and thereby pushes additional oil to a production wellbore, and moreover dissolves in the oil to lower its viscosity and improves the flow rate of the oil. Oil displacement by carbon dioxide injection relies on the phase behaviour of carbon dioxide and crude oil mixture that are strongly dependent on reservoir temperature, pressure and crude oil composition. These mechanisms range from oil swelling and viscosity reduction for injection of immiscible fluid (at low pressure) to completely miscible displacement in high pressure applications. In these applications, more than half and up to two-third of the injected carbon dioxide returns with the produced oil and is usually reinjected into the reservoir by various means.

Nitrogen and gas flooding

Nitrogen and flue gas about 87 % nitrogen and 12 % carbon dioxide is used in place of hydrocarbon gases because of economical reasons. Nitrogen competes with carbon dioxide because it is economical and its compressibility is much lower. For a given quantity at standard condition nitrogen will occupy much more space at reservoir pressure than carbon dioxide and methane at the same condition. Nitrogen has a poor solubility and lower viscosity in oil and requires much higher pressure to create miscibility.

THERMAL RECOVERY

In-situ combustion

Fire flooding is world cheapest means of thermal recovery, however, significant amount of amount of fuel must be burned, both above the ground to compress the air, and below ground in the combustion process. Actually the worst part of the crude oil is burnt, the lighter end are carried forward in advance of the burning zone to upgrade the crude oil.

Stream flooding

In the steam drive, steam Is continually introduced in the injection well to reduce the viscosity of the oil and provide a driving force to move oil towards the production well. Steam driving may work by driving water and oil to form an oil bank in front of steamed zone. Ideally this steam bank remains n front, increasing in size until it is produced by the well offsetting the injector. However, in many cases the steam flows over the oil and transfer heat by conduction. Oil at the interface will then be less viscous and dragged along with the steam to the producing well. Recoverability is increased because the steam lowers the oil viscosity and improves the oil mobility. The more mobile oil displace the steam zone expands vertically, and the steam oil interface is maintained.

Chemical injection

Other techniques which uses heat to improve flow rates (and more rarely) is chemical injection, where polymers are injected to increase the effectiveness of water floods, or the use of detergent like surfactants to help lower the capillary pressure that often prevents oil droplets from moving through a reservoir. Alkaline flooding is an effective chemical EOR method.

SOLVENT RECOVERY

Polymer flooding

Both synthetic polymer such as polyacrylamides and natural polymers are used for improvement of sweep efficiency. Additional polymer makes the water more viscous so that oil is produced faster. Obviously, this is not a good idea n a low permeability reservoir or one with high clay content that absorb the polymer. However, polymer-augmented water floods can be profitable

Surfactant-Enhanced Water flood

Three types of chemical floods exist. The first is an alkaline-augmented polymer flood. Another is an alkaline-surfactant polymer flood. The third is a micellar or low interface tension flood (Donaldson, 1989).

AIM AND OBJECTIVES

The aim of this project is to study the adaptability of anaerobic bacteria (Clostridium Thyrobutyricum 633) to different salinities and check the effect of the microbial strain on permeability of the Danish Nord Sea Chalk.

To achieve this aim, the following objectives have been set:

- Check adaptability of microbial strain to high salinities
- Microbial gas production and dynamics of metabolism
- Carry out plate count experiment
- Observation of fermentation process and microbial analysis
- To determine and measure the volume of carbon dioxide gas produced by these microbes when exposed to different salinities
- To determine the amount of acid produced during fermentation process
- Statistical analysis of results to derive model
- Improvement of experimental procedure

The project work is based on studying of the microbial enhanced oil recovery method and the possibilities of using this in the Danish sector of the Nord Sea. The project task applies experimental procedure and the specific to investigate if these microbes can survive under reservoir conditions and produce products important in oil recovery.

CHAPTER TWO: LITERATURE REVIEW

MICROBIAL ENHANCED OIL RECOVERY (MEOR)

MEOR is used in the third phase of oil recovery from a well, it is a tertiary oil recovery technique. MEOR is the use of micro-organisms to retrieve additional oil from an existing well, thereby enhancing the petroleum production of an oil reservoir. In this technique, selected natural micro-organisms are introduced into oil well to produce harmless by-products like carbon dioxide. These process help to mobilize the oil and facilitate oil flow by reducing the viscosity of the oil and making the rock permeable, thereby allowing more amount of oil to be recovered from a well. Amongst the available tertiary oil recovery techniques, MEOR is arguably the best for many reasons. One key factor in the selection of microbial enhanced oil recovery is the economical potential, by which desirable chemicals and gases are produced to enhance oil recovery. MEOR processes are also energy efficient and environmental friendly as compared to other recovery techniques.

History of microbes used

MEOR is a technology that has a history based on over 60 years of research and field studies. The earlier works by ZoBell CE and Updegraff D (USA), Kuznetsov SI and Shturn DL (USSR), shows the international scope of the work. This work was expanded in the 1950s mainly by investigators Coty VF, Yarborough H and Hitzman DO in the major oil companies in the United States. In MEOR, the process that facilitates oil production is complex and may involve multiple biochemical processes. Microbial biomass or biopolymers may plug high permeability zones and lead to a redirection of water flood, produce surfactants which lead to increased mobilization of residual oil, increase gas pressure by the production of carbon dioxide or reduce the oil viscosity due to digestion of large molecules.

Application of MEOR technologies

MEOR technologies have the common basis of introducing or stimulating viable micro organisms in an oil well reservoir for the purpose of enhancing oil recovery. However, this broad generic definition of MEOR is not a single methodology but is a broader technology which can be designed for different and selective applications. It is convenient to divide the MEOR technology into the following application groups:

- Single well stimulation
- MEOR water floods
- Paraffin's removal
- Viscosity modification
- Water diversion
- Heavy oil modification

The classification of MEOR technology by the proposed oil releasing mechanism shows the range of microbial effects which can be identified or expected to occur to which the MEOR system can be directed.

MEOR Oil Releasing Mechanism

- Gas generation: The production of gases will aid the displacement of oil in the pore spaces.
- Acid production: Organic and inorganic acid production by microbes will dissolve carbonate deposits, iron sulphide and dissolution and sulphate materials.
- Surfactant production: Biosurfactants produced by the organisms result in the reduction of interfacial surface tension of the oil/water bond.

Other MEOR oil releasing mechanisms includes:

- Physical oil displacement
- Biopolymer production
- Hydrocarbon modification
- Viscosity modification

Selective plugging of high permeability zones within a reservoir is necessary to achieve oil recovery. This is best achieved in MEOR process where cells stimulated to grow deeply in a formation where production of biomass and products will have the greatest impact. If growth occurs primarily at the well bore, then face plugging will result, and no additional oil will be recovered, leaving the reservoir unproductive.

The Science of MEOR

The micro organisms used in MEOR can be applied to a single oil well or to an entire oil reservoir. They need certain conditions to survive, so nutrients are often introduced into the well certain intervals. MEOR also requires that water be present. Micro organisms grow between the oil and the well's rock surface to enhance oil recovery by the following methods:

Reduction of oil viscosity: Oil is a thick fluid that is quite viscous, meaning that it does not flow easily. Micro organisms help break down the molecular structure of crude oil, making it less viscous and easier to recover from the well.

Production of carbon dioxide gas: As a by-product of metabolism, micro organisms produce carbon dioxide gas. Over time, these gases accumulate and displace the oil in the well, driving it up and out of the ground.

Production of biomass: When micro organisms metabolize the nutrient they need for survival, they produce organic biomass as a by-product. This biomass accumulates between the oil and the rock surface, physically displacing the oil and making it easier to recover from the well.

Selective plugging: Some micro organisms secrete slimy substances called exopolysaccharides to protect themselves from drying out or falling prey to other organisms. The substance helps bacteria plug the pores found in the rocks within the well so that oil may move past rock surfaces more easily. Blocking rock pores to facilitate the movement of oil is known as selective plugging.

Production of bio surfactants: Micro organisms produce slippery substances called surfactants as they breakdown il. Because they are naturally produced by biological micro organisms, they are referred to as bio surfactants. Bio surfactants act like slippery detergents, helping the oil move more freely away from rock and crevices so that it may travel more easily out of the well.

If we make a comparison between MEOR and other enhanced oil recovery, then we can see that MEOR is much adoptable, it offers multiple recovery mechanisms, low capital and operating cost, while in other enhanced oil recovery techniques, only a specified technology is applicable also has a high capital and operating cost.

TYPES OF MICROBES AND THEIR SELECTION

MEOR has gained much attention in recent times, but it is worth noting that not all microbes can survive in such conditions as found in an oil well, therefore the microbes which are able to withstand these conditions are discussed below:

Microbes used in MEOR

There are many types of bacteria used in MEOR, they include aerobic and anaerobic bacteria and are divided on the basis of their need for oxygen. In this project work, the bacteria used were anaerobic from CHP-biogas plant at Ribe in Denmark.

Selection of Bacteria

The selection of specific bacteria is considered in this method. There are a lot of bacteria available, but the normal conditions for majority of bacteria is 5 % Sodium chloride, optimum temperature of 37 degree Celsius, pH less than seven.

Factors affecting growth of bacteria

There are many factors which affects the growth of bacteria. Some of which are explained in the below:

Salinity: The term salinity refers to the amount of dissolved salt that are present in water. Sodium chloride is the predominant ions in sea water, the concentration of magnesium, calcium and sulphate ions are also substantial. High salinity and toxic substances are responsible for limiting the growth of microbes. Halophiles are salt loving microbes which use sodium chloride and also have complex nutrient requirements. Moderate halophiles can grow anaerobically at temperature greater than 50o C. The salinity in the northern part of Danish oil field is about 40g/l or more. Since salinity too high, formation water is diluted with sea water during injection in the well. In order to perform experimental and laboratory analysis, a sample of produce water is taken so as to know how much salinity can be controlled; therefore microbial gas production has been tested up to 140g/l.

Temperature: Extreme high temperature affects the growth of bacteria, although they need average temperature for growth. Thermopiles are bacteria which are heat loving; these bacteria have an optimum growth temperature of 45 o C – 80 o C. Their membranes are unusually stable at this extremely high temperature. Thus many important biotechnological processes utilise thermophilic enzymes because of their ability to withstand intense heat. So before injecting these bacteria into the reservoir, the temperature of the reservoir should be considered, therefore, selection of the right thermophilic bacteria for high temperature is very important.

Effect of pH: pH is the measure of acidity or alkalinity of a solution. Simply pH is the measure of concentration of hydrogen ions in a solution. It is a measure of the activity of dissolved hydrogen ion. In pure water at 25 o C, the concentration of hydrogen ion equals the concentration of hydroxide ions; this is known as “ neutral” and corresponds to a pH level of 7. 0. Solutions in which the concentration of hydrogen ions exceeds that of hydroxyl ion has a pH level lower than 7. 0 and are known ad bases. The pH reading of a solution is usually obtained by comparing unknown solution to those of known pH, and there are several ways to do so. More favourable pH condition for micro organisms is about 7 and very few of them can grow below2 and above 10. Micro organisms capable of living at very low pH are called acidphilies and those which live at high pH are called alkaliphiles.

Pressure: Extreme pressure affects the growth and metabolism of micro organisms. A pressure lower than 100-200 atm has no effect on microbial metabolism, however, pressure of the range of 500-600 atm have limiting effect on growth of bacteria. The ocean floor possesses high pressure. For most MEOR processes barophilic organisms will not be necessary, instead, barotolerant microbes can grow at high pressures, but do not require these high pressures for optimal growth. The ability to grow pressure depends on the energy sources available, inorganic salts present, pH and temperature. Adaptation of microbial cultures to higher pressure therefore is possible.

Toxic elements: Chemicals which have toxic effects on micro organisms are found in some reservoirs. These chemicals include co-surfactant, surfactant, biocides, ethylenediaminetetraacetate, and toluene, many of which are used in various chemical EOR operations. Sodium and Potassium may be exchanged without impairing the growth of micro organisms. Magnesium has higher toxicity than sodium and potassium, but the most toxic formation water are those with high Calcium Chloride ($CaCl_2$), so adaptability should be considered before injecting micro organisms in such toxic environment.

The choice of Clostridium Tyrobutiricum

Thousands of bacteria have been investigated for MEOR purpose, but the fermentation bacteria remain the most popular especially Clostridia specie because they produce large volume of gas which include CO_2, H_2 and CH_4. These gases produced, decrease the oil viscosity and increase the pressure in the oil reservoir.

Fermentation

Fermentation is the process that produces alcoholic beverages or acidic dairy products. In general, fermentation involves the breaking down of complex organic substances into simpler ones. Waste products formed in this way include gases, ethyl alcohol, butyl alcohol, organic acids, acetone and others. Molasses fermentation generates energy rich metabolic product, which may react in the final decomposition line of sulphate reduction under anaerobic formation condition. With sulphate ion in the formation water, sulphur reduction predominates. Hydrogen sulphide produced is actually not desirable.

The organic acids are formed through fermentation of the molasses by the bacteria in the reservoir do cause a rock dissolving process.

Dorben field (Germany), 1982, Dr. Wagner

Another reason for using fermentation bacteria is Dr. Wagner field trail. If we make comparison between Danish north oil field formation and Zechstein evaporates rocks which are similar to the Danish North Sea formation. Dolomite is also similar to Danish north field chalk. Formation temperature is quite similar and of course has a high salinity. Clostridia tyrobutiricum was selected for Dr. Wagner's experiment.

The characteristics of Dr. Wagner's experiment field are as follows:

- Dolomite of Zechstein formations
- Depth of 1240m
- Formation temperature 53 oC

- High salinity formation water, even the fissures and fractures are partially filled with salt.

The result of Dr. Wagner's MEOR well experiments:

- Water cut decreased from 80 to 60 %

Average annual oil production:

- Before microbial treatment – 50 tons per month
- 3 months after injection – 150 tons per month
- 1 year after injection – 300 tons per month

Since all these conditions are similar to Danish North Sea formation and other factors are also same, so we can use fermentation bacteria for MEOR experiment.

Adaptation of bacteria to high salinities

Majority of the bacteria cannot withstand high salinity, from the time of ancient civilization; it is known that adding 50 g/l of salt in food preserves it from spoiling. This means that fermentation bacteria which normally populate organic substances has a challenge of adaptation in high salinity. The spore forming bacteria like clostridium form spores in extreme conditions. These conditions allow bacteria to survive but they will not be active and would not be productive. Under extremely high salinities, bacteria undergo osmotic stress which is expressed in osmotic pressure. Osmotic pressure affects the water activity and production of CO_2 gas during the fermentation process.

Osmosis

Osmosis is the passage of water from region of high concentration through a semi-permeable membrane to a region of lower water concentration.

Semi permeable membrane are very thin layers of material (cell membrane are semi-permeable) which allow some substances to pass through them and prevent other substances from passing through. Cell membranes will allow small molecules like oxygen, water, CO2, ammonia, glucose, amino acid, etc. to pass through; meanwhile, cell membranes do not allow passage of larger molecules like sucrose, starch, protein, etc.

Osmotic pressure

Osmotic pressure is hydrostatic pressure produced by a difference in concentration between solutions on the two sides of a surface such as a semi permeable membrane. It was also observed that the bacteria change its morphology. For the case of clostridia it will mean that from rod-shape it turns to cocci-form which is simply the reflection of shrinkage.

Potential osmotic pressure

Potential osmotic pressure is the maximum osmotic pressure that could develop in a solution if it were separated from distilled water by a selectively permeable membrane. It is the number of solute particle in a unit volume of the solution that directly determines its potential osmotic pressure.

Osmotic properties of cells

The wall of bacteria and growing plant cells are not completely rigid, and the turgor pressure has been proposed to provide the mechanical force for the expansion of the cell walls during cell growth. The uptake or biosynthesis of osmotically active solutes causes an increase in the cells, thus providing the necessary tugor pressure for expansion of the cell walls. Although the suggestion that turgor pressure is the driving force for cell wall expansion would imply that the mechanisms that regulate the osmotic balance of organisms are central to the very process of cell growth.

Lipid membranes allow rapid diffusion of water molecules into or out of cells while presenting an effective barrier to most other biological molecules. Membranes that exhibit selective permeability for different substances are called semi permeable, and the osmotic properties of cells derive from this property of the membranes.

Thermophyllic and Halophyllic bacteria

There are bacteria which need high salinities and high temperatures for their growth. In order to investigate and record the conditions of microbes at high salinities and high temperature it is better to know about the bacteria which can withstand on these conditions. Important information has been given about these type of bacteria is discussed below.

A thermopile is an extremophile organism which survives at relatively high temperatures. Thermophilic (heat-loving) organisms are organism with an optimum growth temperature of 50o C or more, a maximum of up to 70