Optimizing Oil Recovery Through Microbial Injection To Support TheIncreasing Demand For Oil In Indonesia

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Optimizing Oil Recovery Through Microbial Injection To Support The Increasing Demand For Oil In Indonesia

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Abstract

The method that uses microorganisms to increase oil recovery from reservoir rocks is called Microbial enhanced oil recovery (MEOR). Using this method, the microorganisms are injected to the reservoir and produce the metabolic product which is used in MEOR. There are 6 main metabolic products (bio-products) that can be effected to the reservoir fluid and rock. The 6 main bio-products are bio-surfactant, bio-polymer, bio-mass, bio-solvent, bio-gases and bio-acid. Every bio-product has a different effect on the reservoir and is produced by different microbes, with its purpose being to decrease the residual oil saturation that is left behind in the reservoir rock.

Bio-surfactant can reduce the interfacial tension between oil and the formation water and bio-polymers control the mobility of water that is used in waterflooding. Biomass can plug the reservoir pores and then change the flow direction of fluid flow in the rock. Bio-gas increases reservoir pressure and then forces the oil out of the rocks. Bio-acid can dissolve rock particles and open pore mouths, thus increasing rock porosity and permeability and allowing more fluid to flow, especially in Limestone.

A MEOR field trial was successfully applied at 'X' Field X in Indonesia, involves 10 wells. It can decrease oil viscosity, increase in Oil API Gravity and decrease of the oil pour point. Oil production rate increased from 8 to 66%. Scale is observed as a disadvantage of successful MEOR. The results from this field trial demonstrate that MEOR is potential and offers some benefit to increase oil production.

Keywords: Enhanced Oil Recovery, Bio-Product, Microbes, Oil Reservoir.

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Introduction

The increasing demand for oil as an energy resource to meet demand, combined with evidence of decreasing oil production and limited oil reserves, has created a need to utilize an enhancing oil recovery method as a potential solution to this problem. There has been extensive research about enhanced oil recovery methods, such as chemicals which are using surfactant, polymer or alkaline. Nowadays, we know about Microbial Enhance Oil Recovery (MEOR). MEOR is a method that involves injecting microbes to the reservoir and as a result, its metabolic products will change the physical or chemical reservoir rock and fluid characteristics to increase the oil recovery from the reservoir.

MEOR was first described by Beckman in 1926 and a few studies were conducted on this topic between 1926 and 1940 (Lazar et al., 2007). In 1944, ZoBell patented an MEOR method and continued researching on this subject. The purpose of the research was to find and identify the proper microbes that can be injected to the reservoir and to know their metabolic products (bio-product) and their effect on the reservoir. The growth conditions under where the microbes can live and grow also needed observation.

In practical terms, injecting microbes to an oil reservoir can lead to some restriction in the microbial culture. Microbes have to able to be transported deep within an oil reservoir and be able to proliferate under the reservoir conditions. The nutrients that are needed for growth which aren't available in the reservoir must also be supplied through water injection. As a result, after the nutrients and the conditions are made suitable for the microbes to live, there will be a metabolic process inside the reservoir which creates a bio-product. Principally, there are 6 main bio-products which have a different effect to the reservoir and are produced by different microbes. The 6 main bio-products are bio-surfactant, bio-polymer, bio-mass, bio-solvent, bio-gases and bio-acid.

Until now, MEOR technology and methods are being developed and there are good prospects that this is easy to handle in the field, requires less energy and is suitable for carbonate rock whereas some other EOR methods cannot be applied efficiently. Reservoirs also improve by their growth with time and there is evidence that the microbes bio-product won't accumulate in the reservoir, which is environmentally compatible.

The Mechanism of MEOR

The mechanism of MEOR is similar to other EOR methods, namely it is concerned with changing the characteristics of the reservoir to decrease the residual oil saturation which is left behind in the reservoir rock. The microbes will produce the bio-product through the metabolic process. The 6 main bio-products are described below. Table 1 show the microbes, their bio-product and their applications in MEOR.

Bio-Surfactant

Bio-Surfactant has a positive effect to the reservoir. The bio-solvent can reduce the interfacial tension between water and oil and also bio-solvent can have an effect on the wettability of the reservoir rock. The reducing of interfacial tension between oil and water can create an emulsion. It has been estimated that the interfacial tension must be lowered in the range from 0.01 to 0.001 mN/m to achieve significant oil recovery (Lake, 1989). Bio-surfactant can also change the surface pore wettability of the reservoir rock into water-wet rock. The detachment of oil films from rocks can occur (Dyke, 1991; Li, 2002). With the water-wet rock in the pore surface, it can minimize the friction when the oil mobilises through the rock pore.

Bio-Gasses

Bio-gases are produced by the bacteria that is fermenting the carbohydrate and releases gases such as hydrogen, carbon dioxide and methane gas. These gases can contribute to the pressure buildup in pressure depleted reservoirs. They also dissolve in crude oil and reduce the oil viscosity. The bacteria that produce gases are Clostridium, Desulfovibrio, Pseudomonas and certain methanogens (Behlulgil K, 2003).

Bio-Solvent

Bio-Solvent can reduce the oil viscosity and also contribute in reducing interfacial tension between oil and water.

$$Q = \frac{K.A.\Delta P}{\mu.L} \quad \text{...} (1)$$

The bio-solvents which are produced by the microbe are ethanol, acetone and butanol. Based on the Darcy's Formula, the lower viscosity can increase oil rate:

Bio-Polymer

Bio-Polymer is helping to increase the displacement efficiency in the water flooding method by increasing the water viscosity. The increasing of water viscosity will result in decreasing of the mobility ratio. The mobility ratio is the effective mobility of the displacing fluid behind the front (Mw) divided by the effective mobility of the displaced fluid ahead of the front (Mo). A mobility ratio less than 1 is considered as favorable, and a mobility ratio of more than 1 is regarded as unfavorable resulting in frontal instability and channeling of the water phase. Shown here is the mathematical formula of the mobility ratio:

$$M = \frac{Mw}{Mo} = \frac{K_{rw}/\mu_w}{K_{ro}/\mu_o} \quad \text{.......................................} (2)$$

Bio-Mass

Bio-mass has a similar effect as the bio-polymer, namely it increases the displacement efficiency in the water flood method. Microbes migrate and grow in the pore rock where the water and oil are transported. The mechanism of the microbial biomass in MEOR involves selective plugging of high permeability zones where the microbial cells will grow at the larger pore throats restricting the undesirable water flow through them. This will force the displacing water to divert its path to the smaller pores and hence displacing the un-swept oil and increasing the oil recovery.

Bio-Acid

Bio-acid can increase the reservoir rock porosity, but only in limestone or in sandstone with carbonate cemented. This is because limestone has a carbonate mineral which can be soluble in the acid. The acids that can be produced by the bacteria are lactic acid, acetic acid and butyric acid, which all depend on the bacteria and its nutrient.

MEOR Process

According to the site of the bio-product, there are 2 types of MEOR process:

a. **In-Situ Process**

In this in-situ process, the microbes will be injected to the reservoir, following by its nutrients, and pressed by the water injection process. The bio-product will be produced by the microbes inside the reservoir rock.

b. Ex-Situ Process

The ex-situ process is the opposite of the in-situ process. The bio-product is produced by the microbes in the surface (outside of the reservoir). And the bio-product can then be injected with its microbe or without its microbes.

According to the injection method, there are 2 types of MEOR:

a. Huff and Puff

Microbes and/or its bio-product are injected to the reservoir through the production well. This is illustrated in Figure 1. Huff and Puff Process After the injection process has been completed, the well is shut in for a period of time before it is returned to production. This period usually ranges from 24 hours to 7 days, and this treatment procedure is repeated once every 3-6 months period (J. T. Portwood - 1995).

b. Microbial Flooding

Microbes and/or its bio-product are injected through the injection well and followed by water flooding as the pressure method. This is illustrated in Figure 2. Microbial Flooding. The microbes and/or its bio-product are injected by mixing it into the water injection or in a form of a slug in front of the water injection.

Screening Criteria of MEOR

Before injecting microbes to the reservoir, the microbe should be selected according to the characteristic of the oil reservoir. The following are 3 factors of the reservoir that are used in screening, and are also shown in Table 2. General MEOR Screening.

Reservoir Condition

The high pressure and high temperature inside the reservoir will have an effect on the microbes' life and will proliferate. Based on the Gary E. Jenneman research that the maximum pressure limitation for microbes to live is about 7000-8000 psi, above that the pressure will not have an effect on the microbes life, but will result in a negative impact on the ability of the microbes to grow. And according to the temperature there are 3 type of microbes: Psychrophiles (< 25^0 C), Mesophiles ($25\text{-}45^0$ C), Thermopiles ($45\text{-}60^0$ C).

However, based on the field test data, the microbes can live and proliferate at temperatures of up to 82^0 C in the reservoir conditions (Magot et al., 2000).

Reservoir Fluid Properties

There are 4 parameters from reservoir fluid properties that have an effect on the microbes, namely viscosity, API Gravity, PH and salinity (Wijayanti, 1999). The MEOR mechanism is to increase the displacement and sweep efficiency of the oil. It is more difficult for the microbes and its bio-product to increase the sweep and displacement efficiency in a reservoir with high oil viscosity.

The low oil API gravity or oil which is contained of low volatile fraction also affected to the microbes, It is giving a toxicity effect to the microbes (Wijayanti, 1999).

Commonly, microbes can grow in the pH range from about 2 until 9.5. According to the pH condition, there are 3 types of microbes: Asidophile Microbes (pH 2-5), Mesophile Microbes (pH 5.5-8), Alkaliphile Microbes (pH 8.4-9.5).

Tolerance of microorganisms to salt concentration is one of the most important characteristics needed for microorganisms used in MEOR. The salinity influences the growth, where the microorganisms have to sustain the optimal salinity of cellular fluids to maintain enzymatic action (Madigan et al., 2003). Total salt which is dissolved must not exceed 150000 ppm (Bryant and Burchfield).

Reservoir Geology

Limestone and sandstone with carbonate cementation is the most desirable rock for MEOR. This is because microbes can produce the bio-acid that can soluble the carbonate mineral and increase the porosity and permeability of the reservoir rock (Wijayanti, 1999). Clay mineral can give a negative impact for the microbes, because it can absorb microbes while the microbes transport through the pore which contains the clay mineral.

Porosity and permeability of the reservoir rock can be a transport restriction for microbes. The minimum porosity for MEOR is above 10%, and the minimum permeability is above 50 mD, but the optimum MEOR result is above 150 mD.

MEOR Field Trial

MEOR had been implemented on 10 wells in the "X" Field in Indonesia, (Wijayanti, 1999). The microbe selection was based on reservoir permeability, pressure & temperature data which is shown in Table 3. Clostridium sp. and Bacillus sp. were chosen as the microbes because they can grow in conditions where the temperature reaches 230 ^{0}F and with stand pressure of up to 7000 psi. The lowest permeability in the reservoir is about 0,007-0,38 Darcy in the 8th well. This is based on Table 4. Permeability Range and Pore Size (Kalish et. al., 1964) which illustrates low permeability reservoir rock with 4,5-5 μm pore size. And the Clostridium sp. and Bacillus sp. is required due to the rock pore size, as it has a width of about 0,1-0,3 μm, so it can still transport and grow inside the rock pore. There are 2 types of analysis in this field, the first is analysis of the oil and brines sample, and the second is historical oil production rate data analysis after and before MEOR.

The Oil and Brine Sample Analysis

Based on the oil and brine samples analysis from 10 wells in the "X" Field, there are 4 parameters (oil viscosity, API gravity, pour point, and scale index) which were analyzed. The results were as follows; Firstly, there is a high decreasing of oil viscosity with a percentage of about 13%-31,3% in 6 wells, and a small level of decreasing in oil viscosity in 4 wells with a percentage below 10,5%. Secondly, there is an increase of oil API gravity with a percentage range of 1,5%-9,3% in 5 wells, and low increasing API gravity with a percentage range of 0,5%-0,9% in 5 wells. Thirdly, there is a decreasing of oil pour point with a percentage range of 3%-21% in 9 wells. And lastly, in the brine sample of 10 wells which were analyzed, the scale index is increased. This means the brines can create a scale in the production utilities / facilities and decrease the oil production rate.

Historical Oil Production Rate Data Analysis

In addition to the oil and brine sample analysis, the analysis was also based on the historical oil production rate data shown in Table 5. Oil Production Rate before MEOR and After MEOR. The oil production rate that was analyzed is the oil rate before MEOR and 21 days after MEOR and the results showed that there was an increase in the oil production rate. The highest percentage of the increasing oil production rate is 66% and the lowest percentage is 8%. However, there were 2 wells which showed a declining oil production rate after MEOR and this failure was seen to be caused by the scale problem. In the brine analysis, the scale index increased which is caused by the carbonate mineral that dissolves in the brine and also can be caused by the asphaltic oil. This therefore explains the reason that the scale problem caused the decrease in the oil production rate.

Conclusion

1. MEOR had been implemented in 10 wells on the "X" Field in Indonesia. Based on this field trial, it increased oil production rate from 8 to 66 %.

2. Main displacement mechanism of MEOR changes the physical or chemical reservoir rock and fluid characteristics to increase the oil recovery from the reservoir.

3. Scale will be an important parameter for successful MEOR. It reduces oil production because brine can inflict the scale and deter the hydrocarbons flow to surface.

4. MEOR offers several advantages as compared with other EOR methods such as more environmentally-friendly and it does not consume large energy to inject into reservoir.

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TABLE 1
MICROBES, THEIR BIO-PRODUCTS AND APPLICATIONS IN MEOR.
(McInerney MJ et al., 2002)

Microbial product	Example microbes	Application in MEOR
Biomass	Biomass Bacillus, Leuconostoc, Xanthomonas	Selective plugging and wettability alteration
Surfactants	Acinetobacter, Arthrobacter, Bacillus, Pseudomonas	Emulsification and de-emulsification through reduction of IFT
Polymers	Bacillus, Brevibacterium, Leuconostoc, Xanthomonas	Injectivity profile and viscosity modification, selective plugging
Solvents	Clostridium, Zymomonas, Klebsiella	Rock dissolution for better permeability, oil viscosity reduction
Acids	Clostridium, Enterobacter, Mixed acidogens	Permeability increase, emulsification
Gases	Clostridium, Enterobacter Methanobacterium	Increased pressure, oil swelling, IFT and viscosity reduction

TABLE 2
GENERAL MEOR SCREENING.
(Ahmed Eltayeb et al.,2013)

Factor	Limit	Optimum	Comment
Pressure	Not Critical	-	Extremely high pressure are troublesome to non adapted bacteria
Temperature	$<80^0C$	30^0C-50^0C	Depend on the microbe
Viscosity	>20 cp	-	The upper limiting value wasn't reported

API Gravity	>15	30-40	Heavier crude information wasn't sufficient
pH	5-9	6-8	Main Factor
Salinity	<10% NaCl <150000 ppm	-	-
Lithology	Not critical	carbonate	-
Depth	<7800 ft	-	Depend on the corresponding temperature
Porosity	>10 %	>10%	Not limiting
Permeability	>50 mD	>150mD	-
Oil Saturation	-	>25%	Successful trials with a low saturation was reported

TABLE 3
RESERVOIR PERMEABILITY, PRESSURE & TEMPERATURE DATA
(PT. PERTAMINA UEP III, CEPU)

No.	Well	Permeability (Darcy)	Temperature (^{0}F)	Pressure (Psia)
1	X-1	0,846	138	474,4
2	X-2	1,062	138	372,4
3	X-3	0,160-0,185	152	976,5
4	X-4	0,280	139	643,5
5	X-5	0,280-0,107	152	692,5
6	X-6	0,7-0,846	138	607,1
7	X-7	0,228-0,255	140	900
8	X-8	0,007-0,038	139	887
9	X-9	0,846	145	890
10	X-10	0,107	138	734,4

TABLE 4
PERMEABILITY RANGE AND PORE SIZE
(KALISH ET. AL., 1964)

Type of Permeability	Permeability Range (mD)	Pore Size (µm)
High	278 - 400	5,5 – 6,0
Medium	130 -162	4,5 - 50
Low	17,7 - 48,3	3,5 - 40

TABLE 5
OIL PRODUCTION RATE BEFORE MEOR AND AFTER MEOR
(PT. Pertamina UEP III, Cepu)

No.	Well	Production before MEOR (BOPD)	Production After MEOR (BOPD)	Production Increase	Increase Percentage

				(BOPD)	(%)
1	X-1	5,3	8,5	3,2	60,38
2	X-2	19	30	11	57,89
3	X-3	8,6	10,15	1,55	18,02
4	X-4	28,5	32,4	3,9	13,68
5	X-5	11	6	-5	-45,45
6	X-6	22	29	7	31,82
7	X-7	29	32	2,5	8,47
8	X-8	18,2	22	3,8	20,88
9	X-9	99	93	-6	-6,06
10	X-10	13,2	22	8,8	66,67

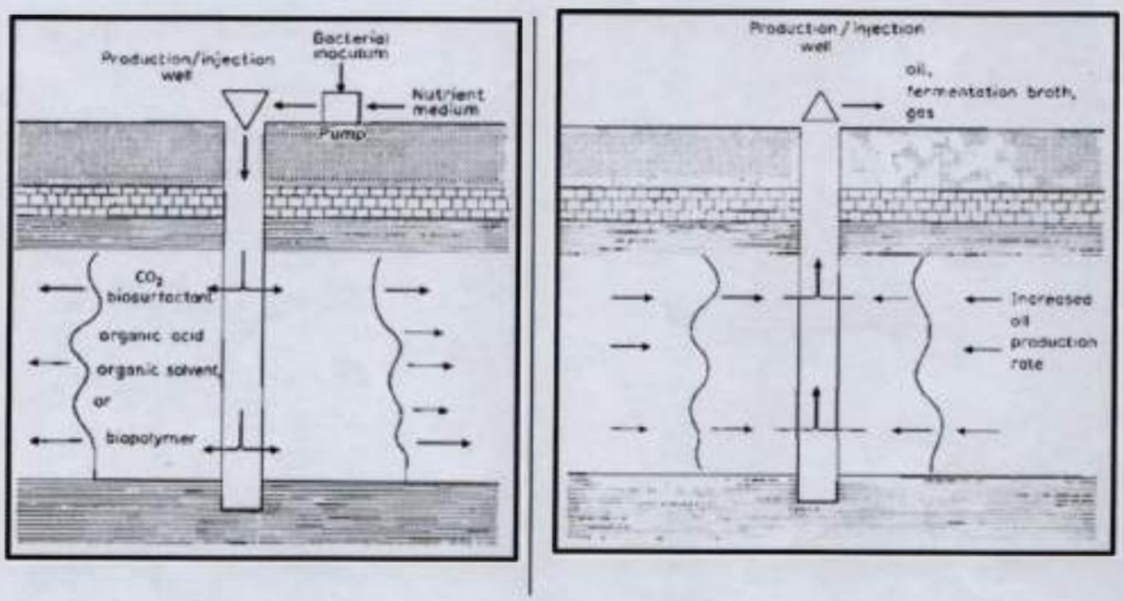


Figure 1 - Huff and Puff Process (Janshekar, 1985)

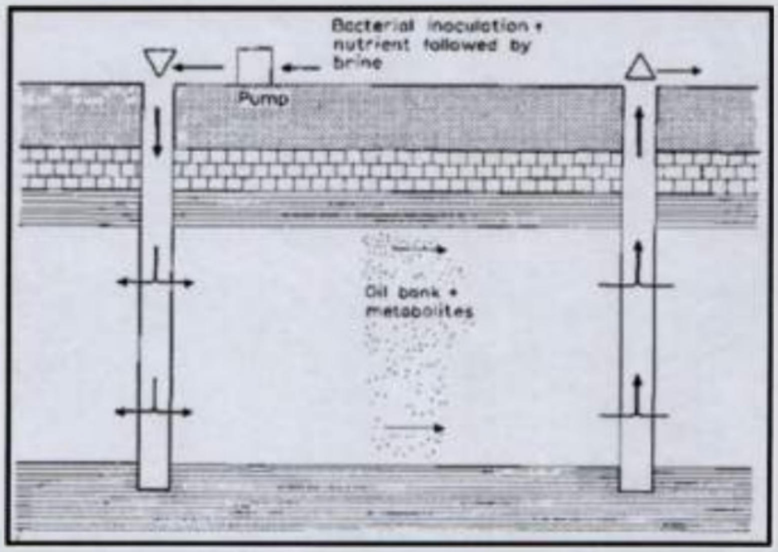
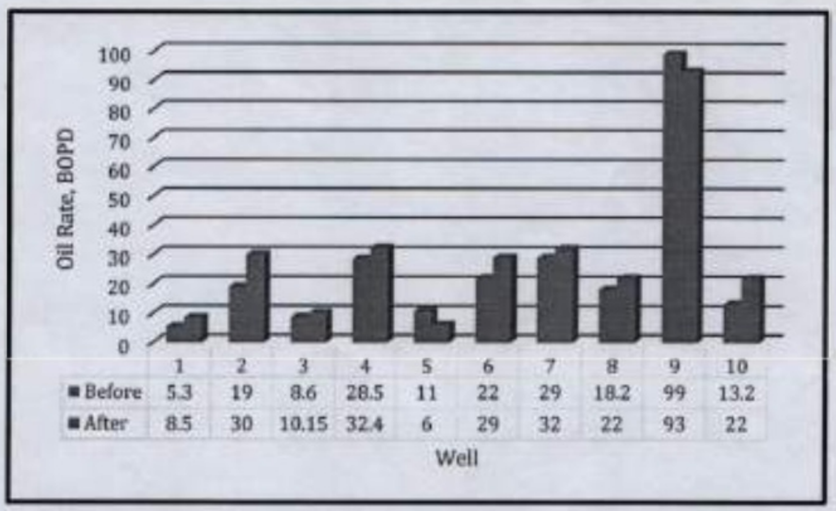


Figure 2 - Microbes Flooding (Janshekar, 1985)

GRAPHIC 1

OIL PRODUCTION RATE BEFORE MEOR AND AFTER MEOR INJECTION

(PT. Pertamina UEP III, Cepu)



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