MICROBIAL EOR STUDY TO IMPROVE SWEEP EFFICIENCY IN CALTEX FIELDS PHASE 1 - NUTRIENT SELECTION

by

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ABSTRACT

The objective of this research is to find a cost effective nutrient that will stimulate the growth of in-situ microbes in Caltex Pacific Indonesia (CPI) oil fields to create sufficient biological products to plug high-permeability reservoir thief zones. If successful, injection fluids may be diverted into unswept regions of the reservoir, increasing the sweep efficiency and extending the production life of watered-out oil fields. This paper describes how a wide range of nutrients were researched and tested in the laboratory to achieve the objective. The primary findings of this study show that several nutrients were successful at creating bioproducts at high temperature, low salinity, reservoir conditions, and that molasses may be the most cost effective nutrient for all three CPI waterflooded reservoirs tested: Balam South, Bangko, and Minas fields. As a result of this work, laboratory studies were started to see to if the microbial growth created in laboratory test tubes can be recreated within reservoir core plugs to achieve sufficient permeability reduction to justify field trial (s). The core flood process and techniques will be presented in a separate paper.

I. INTRODUCTION

Background. Caltex Pacific Indonesia has many waterflood projects in different stages of maturity and so is interested in extending the recovery of these projects through better control of where the injected water goes. Minas is CPI's largest mature waterflood field that has thick producing sands with high heterogeneity and high kv/kh ratio. The high heterogeneity implies thief zones exist (very high permeability zones compared to other zones) that allow reservoir and injected fluids to flow very easily and preferentially through them. Since most of the water injected flows in the high permeability zones, most of the oil in these zones will be pushed into the producer, while oil in the other zones will not. Moreover, due to the uneven velocity of the injection water in the reservoir, also a function of permeability, early breakthrough will occur in the thief zones. Once this happens, water production increases very rapidly and reduces oil movement from other zones.

Isolating zones by mechanical methods is a common practice to reduce water production. But, since Minas has thick sands, high heterogeneity, and high kv/kh ratio, this method is not very effective. Water is only diverted near the injector, so it will still flow predominantly through the high permeability sands as it finds new paths away from the injector and to those sands. The majority of the oil comes from the high permeability regions with greatly reduced sweep effectiveness in the lower permeability sands. Figure 1 illustrates.

Microbial Enhanced Oil Recovery (MEOR). Plugging the thief zones themselves is a better way to reduce the water production and to sweep the remaining oil in the medium and low permeability sands. This process is often called profile modification or profile control because it controls in which sands injected water moves through. Microbial EOR is a method of profile control that takes advantage of the biomass the volume of the microbes themselves, and the bioproducts: biopolymer and wastes, created by the in-situ microbes. A nutrient is injected to enable the microbes to grow and produce enough biopolymer, wastes, and biomass to plug the high permeability zones. A multilayer growth of cells which consists of biopolymers and biomass produced by the microorganisms on a solid surface is called a biofilm (Zhong and Islam 1995). This latter term is thought to be the most effective at reducing permeability however the

growth of microbes in liquid suspension is thought to work as well. The actual mechanism of permeability reduction will be studied in future tests. Figure 2 shows how the microbial profile modification is different from mechanical isolation.

Microbes can be used in a variety of other ways and so the technique must be designed for the reservoir and the application. A variation to the process shown above is to inject both nutrient and microbes into the formation. One application, not considered for the CPI study, is modifying the viscosity of the injected water. Another application, not studied here, is reducing the viscosity of the crude oil. CPI, supported by LEMIGAS (Research and Development Centre for Oil and Gas Technology) has chosen to investigate profile modification for some of its waterflood fields. We are investigating using the microbes found in the formation and injecting nutrients to stimulate their growth.

Economics. The high price of crude oil and increasing industrial capabilities in biotechnological processes have attracted interest in using microbes for enhanced oil recovery. Currently over 1000 oil wells in the USA are now utilizing MEOR to increase their production. This indicates the technical feasibility of using microbes.

MEOR can compete economically with other enhanced oil recovery techniques because MEOR does not require high energy expenditures as in steam flooding, nor expensive chemicals as in chemical or polymer flooding. In MEOR, the needed bioproducts can be created by feeding microbes cheap raw materials such molasses. The bacteria simply multiply themselves without requiring expensive production processes.

A literature database was analyzed to determine the number of successful MEOR projects. It was concluded that 78% of the MEOR projects were successful in reducing the water production rate and showing an increase in oil production.

An economic evaluation of MEOR was made by NIPER in the USA at the Mink Unit oil field and the Phoenix Field in Oklahoma. In the study that was made from 1986 to 1989, microbes were injected with water and succeeded in increasing the production by 13%. The additional cost of production with MEOR was only US $3.24/barrel.

A more extensive study was conducted at the Phoenix field between 1990-1993. In this case, a 19.6% increase in production was obtained, with additional cost of production of US $2.33 per barrel. The cost did not include the cost of microbes and their formulation.

The BOS (Live Oil's Biological Oil Stimulation) method, which was developed in Australia and implemented at various oil fields such as Ninian (Chevron, North Sea), Kuparuk (BP Amoco and Conoco, Alaska), Beatrice (BP Amoco, North Sea) and others, had an estimated production cost per additional barrel of oil recovered at US $1.50 - $3.00. The cost included nutrient, royalty payment, and other commercial charges.

II. EXPERIMENTAL

Materials. The materials, nutrient and supplements, used in the Microbial Profile Modification process are an important part of the evaluation. There are many sources of nutrients such as sucrose, molasses, corn steep liquor, black liquor, soybean whey, tapioca whey, etc. The combination of nutrient with nitrogen, phosphorus, minerals, and proteins is called here "the media." Media were developed by combining different amounts of the materials required for growth. The materials were chosen based on their availability in Indonesia and cost. Seventeen media were screened in the laboratory as shown in Table 1.

Microbes. Semi-anaerobic microbes, native to the formation waters of three fields in CPI: Balam South, Bangko, and Minas, were used in this study. These microbes consist of a mixed culture of various bacteria dominated by the variety known as genera *Bacillus*. The microbes are already found in the formation; they grow naturally in the produced water when exposed to nutrients.

Nutrient. Microbes require for growth sources of the major elements which make up cell material - carbon, nitrogen, phosphorus, oxygen, sulphur, minor components such as iron, zinc, manganese, and a source of energy for the synthesis process involved in growth. For this study, the carbon source came from either of two organic compounds: sucrose or molasses. Organic fertilizer was added as the nitrogen and phosphorus sources.

Water. Formation water varies among reservoirs so this factor was considered as well. Water properties such as salinity, presence of cations, pH, and the presence and type of bacteria can effect how well the microbial process performs for profile control. Samples of both produced and injected water were taken from several wells in each of the three fields and analyzed to ensure that the water could support microbe growth and that the water properties remained the same within a field. Aerobic and anaerobic microbes were counted as well.

Table 1
Lists of Nutrients

No.	Nutrient	Others	Recommendations Remarks
1.	M1	20% of NB composition	No, the growth is not significant
2.	M2	NB modification	No, Slightly increasing viscosity
3.	M3	2% molasses + 1% pepton	No, the growth is not significant
4.	M4	3% molasses	**Yes, good for increasing viscosity**
5.	M5	C & N source	No, Slightly increasing viscosity
6.	M6	5% molasses	No, the growth is not significant
7.	M7	7% molasses	**Yes, good for increasing viscosity**
8.	M8	10% molasses	**Yes, good for high temperature and increasing viscosity**
9.	M9	10% molasses + NPK source	**Yes, good for biopolymer production**
10.	M10	10% molasses + yeast	No, decreasing viscosity
11.	M11	20% molasses	No, not usable, because will produce caramel
12.	M12	20% molasses + supplement	No, not usable, because will produce caramel
13.	M13	7% molasses + 10% N source	**Yes, increasing viscosity**
14.	M14	7% molasses + 15% C source	No decreasing viscosity
15.	M15	7% molasses + 10% N & P source	**Yes increasing viscosity**
16.	M16	4% C + 0,1% N + 2% mineral	**Yes, significant growth at high temperature**
17.	M17	0,25% N source + 5% C source	**Yes, growth at high temperature**

Table 2
Reservoir & Test Temperature

Reservoir	Temperature
Balam South	145°F
Bangko	192°F
Minas	207°F

Table 3
Composition of Nutrients Tested

L1	• 100 ml molasses • basal medium
L2**	• 10 g N source • 50 g C source • 20 g mineral • basal medium
L3**	• 10 g N source • 10 ml C source • basal medium
L4*	• 30 g N source • 20 g C source • basal medium

III. PROCEDURE

Water Compatibility. The MEOR study began by screening the many and various nutrients for their compatibility with the injected water. If a nutrient formed particles or precipitated in the field injection water during the 24 hour test, the nutrient was discarded. This initial screening was to prevent plugging at the wellbore during media injection.

Nutrient Development. Many tests were conducted to determine the best recipe of nutrients and supplements for achieving microbial growth and bioproduct production.

The screening was a 28 day test with measurements made on day 0, 3, 6, 12, 20 and 28. The procedure was to cultivate the indigenous microbes in a test tube at reservoir temperature (see Table 2) with the test media and then to sample the medium on schedule. The medium for cultivation or incubation consisted of the produced water, crude oil, and the media. The media to be tested was mixed with produced water and crude oil in a container, sealed, and raised to reservoir conditions. At the time intervals given, a small sample was pipetted and looked at under a microscope. The same tests were performed for each field.

Microbe and nutrient performance were gauged by the microbe population growth using the plate count method, the increase in viscosity, and changes of acidity using a pH meter. After the screening studies, the best performers from the original 17 were each tested further using the same procedure and measurements but included measuring turbidity by spectrophotometer.

Shut-in Tests. When the best nutrient/media recipes were found by the experiments above, they were tested again to determine the optimum growth time using the same procedure but with the additional performance measures of biopolymer quantity using a gravimetric method, gel strength and growth curve. Gel strength is an indication of the strength and stability of the biopolymer under reservoir conditions. It was measured by adding 5 mL of the medium into a test tube, sealing it, raising the temperature to reservoir conditions and watching every few days to see if a gel formed.

The tube was tipped on its side and the movement of the gel was observed and measured. The growth curve was obtained as before by counting the microbe population using the plate count method at the end of each period.

Table 4
Optimum Shut-in Time

Field	L1	L2
Balam South	Not tested	9 days
Bangko	Not Tested	15 days
Minas	16 days	10 days

IV. RESULT AND DISCUSSION

The activities of the study consisted of two parts; namely 1) Screening and developing the media recipes, and 2) Measuring the gel strength and growth curves of the best media to determine the optimum growth time.

Water Compatibility. All nutrients were compatible with the injected water.

Nutrient Development. The ultimate purpose of the nutrient development experiments was to create a media that yielded the optimum biopolymer and biomass for plugging thief zones. It was originally thought that an increase in viscosity of the water was a good indication of biopolymer production. In discussions among LEMIGAS, CPI, and an MEOR consultant, it was determined that viscosity increase was not a precursor to plugging the high permeable zones and that rather, microbial growth and biopolymer production were the best factors. Only the nutrients from Table 3 that showed microbe growth were used for further testing. The three best nutrients for microbe growth were labeled L1, L2, L3. A fourth nutrient, L4, was a variation on L2. Three of the four, L1, L2 and L3, went through several variations in recipe as different experiments were ran. Table 3 shows the final composition of the four nutrients.All four nutrient were tested in every field water.

Two media, L1 and L2, gave the best result for microbe population growth and biopolymer production in the nutrient development tests. Medium L1 used a molasses-based nutrient and L2 used a sucrose-based nutrient. Both media, L1 and L2 were compatible with all produced water samples. Only the L1 and L2 results will be shown.

Numerous indigenous microbes are capable of synthesizing a variety of biochemical products in formation water. The range of metabolic products from microbial growth is very broad, depending on environmental conditions (temperature, pH, salinity, and the presence or absence of oxygen), supporting nutrients available for cell metabolism (nitrogen, carbon, phosphorus, mineral, etc.) and the specific bacteria

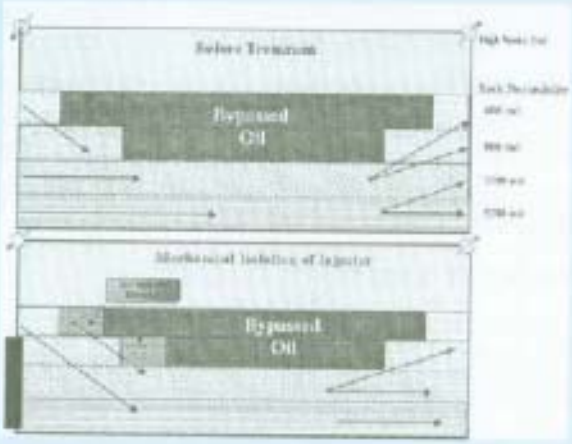

Figure 1
Waterflood Process and Mechanical Isolation of Injector

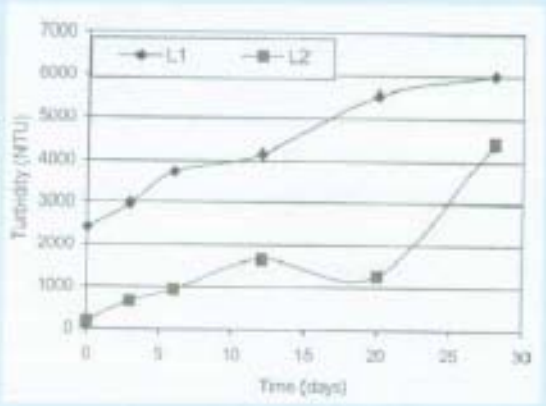

Figure 4
Growth Curve, (L1, Minas)

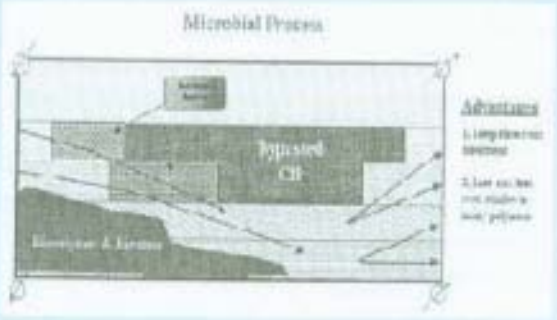

Figure 2
Waterflooding with Microbial Profile Control

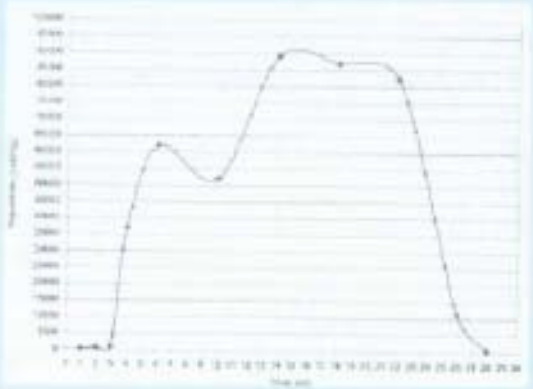

Figure 5
Growth Curve (L2, Bangko)

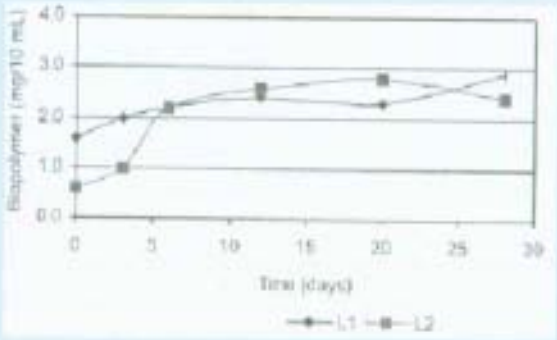

Figure 3
Biopolymer Production with Time

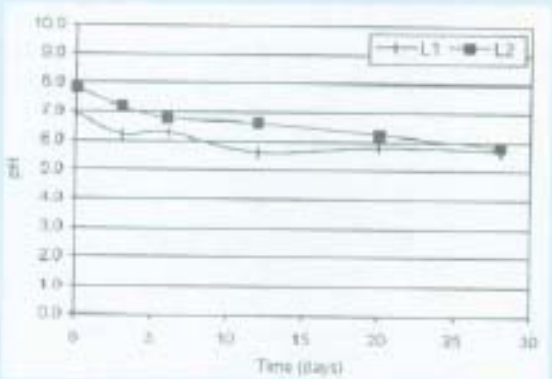

Figure 6
Change in pH with Time

interacting in the formation water.

One of the bioproducts of the most interest for this application are biopolymers. The chemical structures of most of the high molecular weight polymers produced by microbes have not been completely defined because of their molecular diversity and complexity.

The result of biopolymer production during 28 days incubation with the L1 and L2 media is shown in Figure 3. Biopolymer mass in both media increased. The production of biopolymer is related to the growth in microbial population. The trend of both curves, biopolymer production and growth, is similar. The growth curve in medium L1 is shown in Figure 4 and growth curve for L2 in Figure 5. Note that the formation water is given as well.

During the growth of the microorganisms in the L1 and L2 media, the pH decreased over time (Figure 6). Microbial metabolic activity can create wastes or byproducts which lower the pH. Numerous kinds of bioacids can be produced by bacteria, however in this study, a bioacid product was not detected. Acidity was measured as another sign of microbial activity.

The produced water viscosity is shown in Figure 7. The viscosity of produced water was low and remained stable for the 28 days of incubation in every test for L1 and L2.

Another parameter monitored for microbial activity was turbidity. This parameter is used for measuring biomass or particles suspended in the water. From Figure 8, the turbidity increased in both media L1 and L2. This result indicates that additional biomass in the liquid medium may be available for plugging.

Shut-in Experiments. The shut-in experiments determined the optimum time for the microbes to form a biopolymer which would modify the injected water profile. The parameters measured for the shut-in tests are gel strength and growth curve.

The result of the gel strength tests was that only the LEMIGAS medium no.2 (L2) formed a precipitate with any strength after 7 days. Therefore, the growth curves were used instead to determine the optimum time for growth. Table 4 shows the shut-in time required for maximum growth.

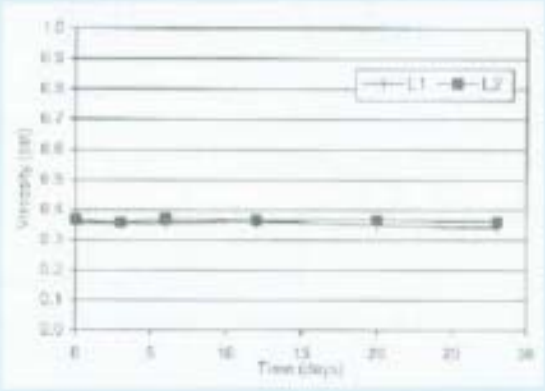

Figure 7
Water Viscosity with Time

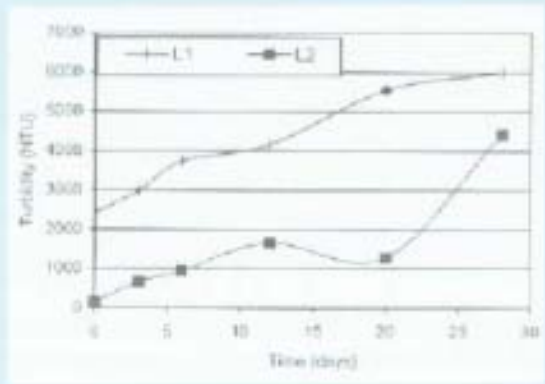

Figure 8
Turbidity

V. CONCLUSIONS

A system consisting of nutrients, supplements, and formation water was found which promotes microbial growth with the accompanying production of biopolymer and biomass. The growth occurred under reservoir conditions in test tubes but now must be tested for its ability to grow and plug high permeable cores and divert injected water. The sucrose-based nutrient worked best however it is significantly more expensive than the molasses-based nutrient.

MEOR appears to be technologically and economically promising according to the literature. MEOR is easy to apply, and generally requires little modification of the existing production/injection facilities. If it can work in CPI's fields, it promises a significant improvement in recovery.

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