FIELD TEST OF THE INDIGENOUS MICROBES FOR OIL RECOVERY, LEDOK FIELD, CENTRAL JAVA

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ABSTRACT

After selecting several old wells in Cepu, then well LDK-132 was chosen for implementing MEOR technology using "huff and puff" method. For this purpose, fluids samples (water and oil) from Ledok Formation were taken at the wellhead. No core of LDK-132 was available, only cores from LDK-209 and LDK-P1 were found. Core plugs could not be made from the former due to compacted and tightly conditions with a very low permeability of only 0.458 md. The latter with the permeability of 140 md met the requirements of microbial core flooding (MCF) tests. A standard quartz dominated core from Clashach Scotland with permeability almost 800 md was also used to compare with the native core's results. The MCF tests were conducted at the reservoir conditions for both types of core. The native core gave a recovery factor of oil production of 12.58%, while the standard core yielded a higher recovery factor of 21.22% of Sor. Based on these results, the MEOR implementation was conducted on July 8, 1999 by injecting 135 barrels of mixtures consisting of formation water, microbes enriched with KKL-11 (Koleksi Kultur Lemigas or Lemigas Cultures Collection) and M4⁺ medium through the annulus of LDK-132. The result showed an increase of average oil production rate, from 3.46 bopd, 6 days before the injection, to 24.85 bopd, 6 days after the injection.

I. INTRODUCTION

The petroleum resources in Indonesia have been naturally depleting since more than 100 years of exploi tation. In general, the average oil recovery from the first and second phases of production is still rather low, i.e. between 30 and 40% of original oil in place (OOIP). The remaining oil is still trapped in the reservoir rocks' pores. To obtain this oil and to improve the recovery of oil fields in Indonesia, the EOR methods should be applied. Microbial enhanced oil recovery (MEOR), among others, has drawn attention to this application due to recent developments in biotechnology. This technique is highly relevant for Indonesia, if related to its diversity of tropical microbes. Certain thermophilic anaerobic microbes, for instance, have an ability to grow well in the reservoir conditions and also have an adaptability to develop in the oil-bearing formation, which has large surface area to host or act as habitat of microbe colonization.

Cepu oil field, located of about 180 km to the east of Semarang, the capital city of Central Java (Figure-1), was given by PERTAMINA for MEOR implementation using "huff and puff" method. Well LDK-132, in Ledok structure, was selected among sixteen existing candidate wells for the first test, because it fulfilled the criteria of MEOR requirements such as salinity < 19%, water cut > 70%, oil gravity > 15°API, total depth < 1000 m, porosity > 3%, and permeability > 20 md.

Laboratory tests on the fluid taken from the well head indicated that the bio-products produced by the indigenous microbes of LDK-132 in $M4^+$ medium were able to make some changes to their parameters such as the interfacial tension (IFT), acidity (pH), and viscosity. The changes on these particular parameters were useful for increasing the oil production of the well.

MCF tests at the reservoir conditions on the native core LDK-P1 with the indigenous microbes from LDK-132 and $M4^+$ medium gave a recovery factor of 12.58% of Sor, and permeability decreased from 3.80 md to 1.82 md, or permeability reduction factor of 52.11%. The same media and microbes tested on the standard core with similar conditions gave a better recovery factor, i.e. 21.22% of Sor, and permeability decreased from 36.40 md to 30.40 md, or permeability reduction factor of 16.48%.

The first cycle of injection, approximately 135 barrels of formation water containing indigenous microbes plus KKL-11 (as a starter) and M4$^+$ medium were performed on July 8, 1999 through the annulus of well LDK-132, with the total depth of 186 m. This mixture was pumped into Layer-111 of the Ledok Formation with the porosity of 26.60%, permeability 300 md, temperature 55.60°C, which contained paraphinic oil. After being shut in for 1 week, the well was returned to production. The production rate could not be fully optimized due to the mechanical problems of the pump unit. In 6 days, since July 29 1999, the average oil production rate was only 3.46 bopd, but a serious mechanical pump problem emerged. During the week, after August 20, 1999, the oil production suddenly increased to 22.02 bopd, 31.45, 22.64, 21.39, 15.10, 12.58, and 9.44. Unfortunately, the next cycle of nutrient injection to monitor the progress of this implementation could not be continued, because the pumping unit was needed for other more productive well in this field. LDK-132 itself was given to the local cooperation unit for stimulating their activity to support the government policy.

II. LABORATORY EXPERIMENTS FOR FIELD APPLICATION

Tube Scale Tests. The aim of these tests upon the fluids samples is to observe the changes on microbes' population, IFT, viscosity, and pH due to microbes' activity.

The observation of the microbes population on the mixed cultures of LDK-132 plus *Bacillus cereus* enriched with KKL-11 in M4$^+$ medium were done for 7 days of incubation time at temperature of 55.60°C and anaerobic conditions. There was an increase of the population from 27.8 x 10^2 cell/ml to 300.0 x 10^2 cell/ml.

The effect of microbes' activity on IFT between paraphinic oil and formation water in anaerobic condition and temperature of 55.60°C was also conducted. The test on mixed cultures of LDK-132 indicated a decrease on IFT from 8.72 mN/m to 5.46 mN/m, or 37.39%.

Another test on the same mixed cultures of LDK-132 indicated a decrease on viscosity from 4.05 mPas to 3.77 mPas, or 20.90%. The effects of these cultures at similar conditions indicated a decrease on pH of 28.33%.

Microbial Core Flooding Tests. The purpose of these tests is to obtain the estimated recovery factor as a reference before the field application. If the recovery factor < 10%, the implementation is categorized as not feasible. Before testing, the available cores need to be measured first to determine their porosity and permeability, minerals composition through XRD (X-Ray Diffraction), and also pores' structures by SEM (Scanning Electron Microscope).

Only two cores were available for the flooding tests, i.e. native core LDK-P1 from Ledok and a standard core Clashach from Scotland.

Native Core. The first core, LDK-P1, has an absolute permeability (K_a) of 140 md, porosity 34.12%, water volume in the rock pores 23.20 ml (after saturated with water), permeability to water (K_w) 27.80 md, and initial oil volume (S_{oi}) 16.05 ml, or 69.20% of pores volume (after the flooding). Residual oil saturation (S_{or}) of 7.95 ml, or 49.50%, was obtained after conducting the water formation flooding. This makes possible to calculate the permeability to water, giving K_w 3.80 md @ S_{orwf}.

Next, with the flooding of microbes from LDK-132 yielded a total oil recovery of 1.00 ml, or 6.23% of OOIP. Oil recovery factor (RF) was 12.58% obtained from the calculation using the following formula:

$$RF = \frac{S_{orwf} - S_{ormf}}{S_{orwf}}$$

where:

RF = recovery factor

S_{orwf} = oil saturation after water injection

S_{ormf} = oil saturation after microbes injection

Permeability to water should be measured, giving K_w 1.82 md @ S_{ormf}. Permeability reduction factor (PRF) can also be estimated, i.e. 52.11%. This high value resulted from fines migration through the effects of flooding injection and microbes' bio-products.

Standard Core. The flooding test process for the second core, Clashach, was similar as on the native core. From the laboratory measurements could be obtained the following parameters: core's pores volume 13.73 ml, initial oil saturation 9.70 ml, or 70.67% of pores volume. After injecting the formation water, the oil recovered was 5.93 ml, or 61.10% OOIP. After microbes injection, the total oil recovery was 0.80 ml, or 8.25% OOIP. This meant that the recovery factor was 21.22% of S_{or}. The changes of permeability to water for K_w @ S_w = 100% was 465 md, for K_w @ S_{or1} was 36.40 md, and for K_w @ S_{or2} was 30.40 md. This gave permeability reduction factor of 16.48%, because the standard core was more stable core compared to the native core.

In general, the microbes flooding tests on both kinds of cores gave a very good result, since the oil recovery on laboratory scale yielded a recovery factor higher than 10%. Flooding results and permeability changes during the injection process are depicted in Tables-1 and 2, while the plot of the flooding results are shown in Figures-2 and 3.

III. FIELD TEST DESIGN AND PROCEDURE

In the design of MEOR process, the nutrients were injected into Layer-111 of Ledok Formation to stimulate the *in-situ* production of bio-chemicals that can be used to recover the oil that remained in the layer. The nutrients used in this particular MEOR process are predominantly molasses, which is not only inexpensive, and readily available, but also environmentally safe. Although often used, this molasses has several disadvantages for MEOR. Since molasses is a waste product of the refining of sugar cane, its chemical composition is variable and undefined. Consequently, the predictability and consistency of the expected biological products decreases, and also it is difficult to predict the transportability and utilization of these undefined nutrients at depth of the layer. In addition, molasses contains suspended particles that could reduce the injectivity into the layer (Grula, 1985 and Coombs, 1987).

In general, as rules of thumb, in the conventional continuous water injection, the amount of water that will be injected into the producing well is proportional with the thickness of the layer injected, i.e. between 5.0 bwpd/net ft and 15.0 bwpd/net ft (Gomaa, 1998). Thus, if the thickness of the formation is 31 m, or 101.71 ft, for instance, that means the fluid injected ranging from 246 bwpd to 738 bwpd.

In the initial condition (see Table-3), the water in the tubing's column is assumed immobile, i.e. 3.63 barrel, and the water in the casing is 34.91 barrel, so the water in the annulus is 31.28 barrel. Due to the effect of the reservoir pressure, the water volumes are 4.58 barrel, 44.11 barrel, and 39.53 barrel in the tubing, casing and annulus, respectively. In order to fill the annulus' whole space, a total of at least 40 barrel, should be injected. In the field operation, first 45 barrels nutrient and water formation mixtures were injected through the annulus into the Layer-111. The reason behind this is to make

Table 1
Oil recovery through microbes flooding

No.	Core Sample	Pore Vol. (cc)	Initial Water Saturation		Initial Oil Saturation		Oil Production Water Injection		Type of Microbe	Shut In (days)	Oil Production Microbes Injection		Oil Rec. Factor
			(cc)	% PV	(cc)	% PV	(cc)	%OOIP			(cc)	%OOIP	
1.	LDK-P1	23.20	7.15	30.80	16.05	69.20	8.10	50.10	LDK-132 +BC	21	1.00	6.23	12.58
2.	Clashach	13.73	4.03	29.33	9.70	70.67	5.93	61.13	LDK-132 +BC	16	0.80	8.25	21.22

Table 2
Water permeability through microbes flooding

No.	Core Sample	Ka (md)	Kw (md)	Kw@Swc (md)	Kw@Sor1 Water Inject. (md)	Kw@Sor1 Micr.Inject. (md)	Permeability Reduction Factor (%)
1.	LDK-P1	140.00	27.80	15.80	3.80	1.82	52.11
2.	Clashach	792.70	465.50	429.50	36.40	30.40	16.48

Table 3
Reservoir Data of Well LDK-132 (per 8 July 1999)

Field Data	
Operation Region	Cepu
Formation	Ledok
Structure	Ledok
Well Number	LDK-123
Layer Depth	153 m (501.99 ft)
Block/Layer	-/L III
Reservoir Data	
Perforation	155-186 m
WOC	42 mbsl
Oil Rate	1.2 m^3/d (7.55 bbl/d)
Cum. Oil Production	54.929 m^3 (345.503 bbl)
Remaining Oil Reserve	195.23 MSTB
Perforation Pressure	95.60 psi
Bottom Hole Pressure	No Data Available
Gross Thickness	52 m (170.60 ft)
Porosity	26.60%
Permeability	300 md
Temperature	64.20°F (29°C)
Water Cut	7.10%
Water Saturation	50%
Sg	33.2°API
Gradient	0.43 psi/ft
Initial Condition	
Tubing volume	105.11 ft^3 (18.72 bbl)
Casing volume	623.10 ft^3 (110.98 bbl)
Annulus volume	517.99 ft^3 (92.26 bbl)
Effect of Reservoir Pressure	
Reservoir pressure	580 psi
Water column height	1423.84 ft
Tubing volume	64.16 ft^3 (11.43 bbl)
Casing volume	380.33 ft^3 (67.74 bbl)
Annulus volume	316.18 ft^3 (56.31 bbl)
Minimum Volume Injected	148.57 bbl

sure that the standing water of 31.28 barrel were really pushed into the reservoir. Then, another 45 barrel of molasses and water formation blend were injected to replace the first volume in the annulus. Finally, 45 barrel of plain water formation was injected to flush the molasses deep into the reservoir.

Thus, the total amount of formation water and nutrition injected into the well LDK-132 was approximately 135 barrel. Even these figures are less than 246 barrel, but the assumption of the volume was quite enough to produce bio-products in the vicinity of the well bore. If the volume was much less than 135 barrel, the fingering effect might be occurring. This was the unwanted condition.

MEOR injection involves the utilization of microbes where their metabolic products were able to increase the oil recovery. To succeed the whole MEOR operation, however, care should be taken in the general injection procedure that can be given as follows:

1. Sand grains in the bottom of the well should be cleaned up first to allow the fluid injection freely flow into the layer.
2. Inject 135 barrel, the mixture of nutrients and formation water that can propagate better into the layer, so that the fingering effect cannot occur.
3. Shut the well in for about one week.
4. Re-open the well, produced with the rod pump. Record the oil production rate and the water rate as well. Monitor the production until certain level at the separator test.
5. If necessary, re-inject the nutrients and formation water, as indicated through monitoring result.
6. After that, repeat the steps nos. 3, 4 and 5.

IV. FIELD TEST RESULTS

After being shut in for one week, the well was then returned to production on July 15, 1999. The production record cannot be observed smoothly because of the mechanical pump unit problems. That is why in the early stage of monitoring, the average oil production rate is still low, i.e. around 3.46 bopd. In the whole week after August 21, 1999, the averaged oil production rate is 20.86 bopd, an indication of significant increase of oil production.

The microbes injected into the target layer can usually be detected in the produced water. If the results showed that the microbes injected into the well could live and grow in the particular layer for a long time, this

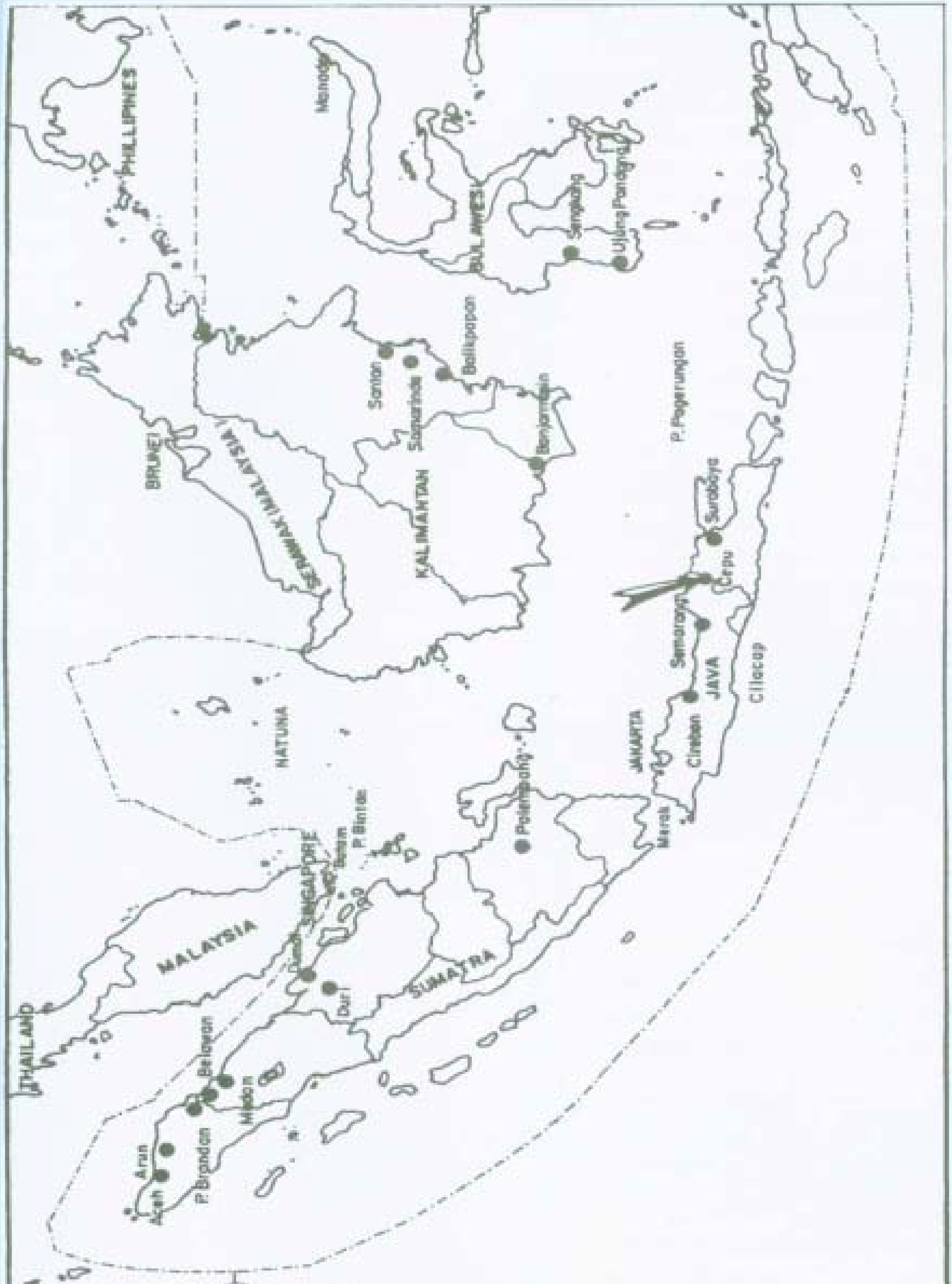

Figure 1
The location of Cepu oil field

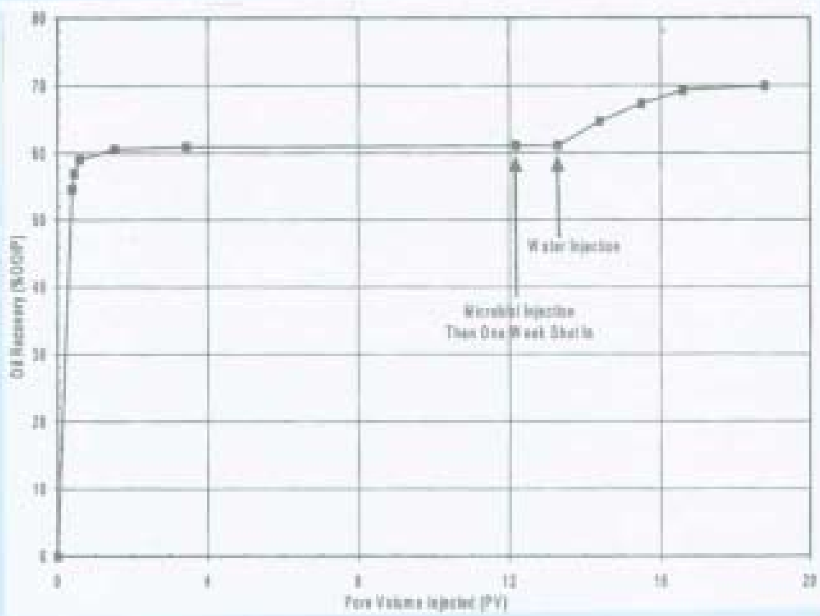

Figure 2
Microbial core flooding test native core LDK-P1

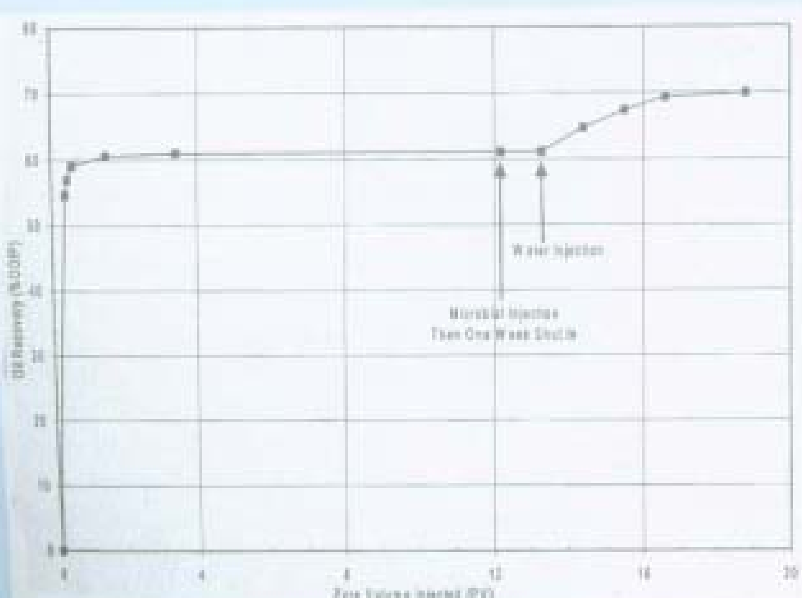

Figure 3
Microbial core flooding test standard core classach

means that the production could continue over an extended period.

The increased organic acid content in the water produced from treated well could also be detected. If, for instance, the oil-water IFT decreased as well, these changes were often useful in helping to displace the oil.

Generally, the increased CO_2 content in the gas produced from the well could also be assessed. The increasing CO_2 provided not only the energy to displace the oil, but also could improve the oil's property.

V. ECONOMICAL ASPECTS

Limited economic parameters of this field test denoted that the major cost of MEOR would be the nutrient factor that supports the life of microbes. To determine the total cost for obtaining the incremental oil for LDK-132, some assumptions should be made, for example the cost of equipment for the microbial injection, which was around $ 1500, no overfeeding the microbial population was done, while the cost for research and development of the microbial formulation was not estimated yet.

In 6 days, from 21 to August 27, 1999, the cumulative oil production was 149.09 barrel. While in 6 days before, the cumulative oil production was only 20.75 barrel. If the production is assumed constant in the 6 days after, then the amount of incremental oil production during 6 days was 128.34 barrel (149.09 barrels - 20.75 barrels). If the oil price is $ 20.00/bbl, this amounts to $ 2566.80 of gross income. If $ 1,000 was allocated for injected nutrient, the cost of the injection facilities was $ 600, and the cost of technicians was $ 400, then a total of $ 2,000 was spent for 1 cycle of the microbial flooding activity, leaving $ 566.80

of additional income, monitored only during 6 days of peak production.

VI. CONCLUSIONS

1. The results on the indigenous microbes of well LDK-132 enriched with *Bacillus cereus* and mixed with M4$^+$ medium showed that their bio-products were able to change the IFT, pH, and viscosity. This was an indication of their usefulness for increasing the oil recovery.
2. Microbial core flooding test conducted on native core of LDK-P1 using the indigenous microbes from LDK-132 enriched with *Bacillus cereus* and M4$^+$ medium yielded a recovery factor of oil 12.58% and a decreasing permeability from 3.80 md to 1.82 md, or a permeability reduction factor of 52.11%. This is due to fines migration through pore spaces and leaving behind a larger pore in the reservoir rocks as revealed by XRD and SEM analyses results.

   The same test on standard core of Clashach gave a recovery factor of 21.22%, and a decreasing permeability from 36.40 md to 30.40 md, or a permeability reduction factor of 16.48%. This relatively low value is caused by the main composition of the core, i.e. quartz, which is more stable compared to clay mineral.
3. After the injection, the average oil production rate increased from 3.46 bopd to 24.85 bopd.
4. In order to obtain the optimum incremental oil, care should be taken in preparing the nutrients, and the injection procedure should also be followed properly.
5. The total expenditures for the injection is $ 2,000 covering the nutrient, technician and rental of pumping unit, and if the oil price was assumed $ 20.00/bbl, then the incremental oil of 128.34 barrels would give $ 2566.80, the remaining amount would be $ 566.80, during 6 days of observation.

VII. ACKNOWLEDGEMENTS

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