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Challenges of MEOR Implementation in Indonesia

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Abstract

The target of oil production Indonesia in 2030 has been set at 1 million bopd. Opportunities and challenges to achieve these production figures are certainly not easy. One of these efforts is the application of EOR methods.

Microbial Enhance Oil Recovery (MEOR) technology is one of the EOR methods by utilizing microbes that will degrade types of oil to make it easier to flow as well as a producer of bio surfactants that can reduce surface tension or internal force tension (IFT). Before implementing MEOR, screening is carried out which includes reservoir parameters, selection the type of microbes to be used and proper nutrition. All over the world this technology has been tried in 17 countries with positive results in 10 countries.

Several fields in Indonesia have been tested for MEOR implementation, including Cepu, Ledok, Bentayan and Mangunjaya. MEOR implementation is carried out with the Huff and Puff system of nutrient injection and microbial injection in production wells. The problem in implementing MEOR is the selection of appropriate nutrients and microbes, besides that when implementing the huff and puff system it takes a relatively long time for soaking. To maintain the production of huff and puff wells, it is necessary to repeat the injection work.

The factors that support this success are reservoir screening, nutrient selection and injection technique. The results of laboratory tests in 3 fields showed that MEOR resulted increasing Recovery Factor (RF) more than 10% and from the implementation of huff and puff in 4 fields, it showed a decrease in water content and a gradually increasing production after soaking.

Keywords: MEOR, Microbe, Nutrient.

Introduction

The target of oil production Indonesia in 2030 has been set at 1 million bopd. Opportunities and challenges to achieve these production figures are certainly not easy. One of these efforts is the application of EOR methods.

Microbial Enhance Oil Recovery (MEOR) technology is one of the EOR methods by utilizing microbes. Increasing production from the MEOR application occurred as a result of a decreasing in oil viscosity, an increasing in API gravity, and a decreasing in pour point *(Harry Budiharjo et al (4)*). MEOR applications in Indonesia have implemented in several fields, including Prabumulih (1992), Klamono and Kawengan (1993), Ledok (1999), Chevron Pacific Indonesia (CPI, 2001), Bentayan (2017) and Mangunjaya (2017). From several fields that have been carried out by MEOR in Indonesia, production increases ranging from 8-66%. The increasing production occurs after some time from the moment of injection.

This paper aims to provide an overview of MEOR cases in Indonesia, MEOR requirements, types of microbes for MEOR, optimal conditions for microbial development in reservoirs, nutrient injection and several fields that potential for MEOR candidates. The writing is based on a literature study of several papers on MEOR and some data from the fields.

MEOR Technology

MEOR is one of the EOR technologies aimed to increasing oil recovery by injecting nutrients and microbes into the reservoir. In the presence of nutrients, microbes in the reservoir will thrive. In addition to degrading hydrocarbons into lighter oils, microbial metabolism also produces gases, acids, biomass and polymers. Gas produced by microbes, it could be rising up reservoir pressure and decrease oil viscosity by dissolving it. Acid could dissolve carbonate. Biopolymer could increases water viscosity in water flooding activity.

An increase lots of microbes could also cause plugging in the oil zone and acid can cause corrosion in equipment.

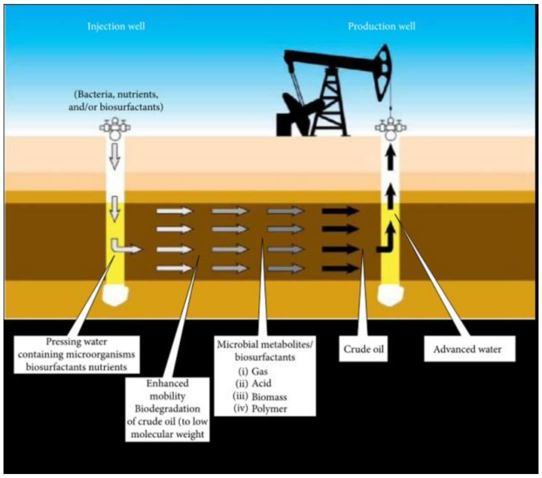

Figure 1 – MEOR Process in Reservoir. *Haicheng She et al. (3)*

Based on the use of MEOR, the process is divided into several there are including microbial flooding recovery (MFR), cycle microbial recovery (CMR), microbial selective plugging recovery (MSPR), and others. According to the strain, it is divided into 2, namely Indigenous and Exogenous. Indigenous microbes come from reservoirs. Exogenous microbes are selected and come from outside the reservoir. Currently, the most developed microbes are indigenous microbes because they are more adaptive and avoid the use of microbes from outside.

Based on the growth that needed oxygen or not, it could be divided into aerobic bacteria, facultative bacteria, and anaerobic bacteria. Based on their effect on oil production, there are microbes in the reservoir that are good for oil production and some are not. To detect microbes, complex high-tech biotechnology equipment is used, such as terminal restriction fragment length polymorphism (T-RFLP), gene bank, denaturing gradient gel electrophoresis (DGGE) and most probable number (MPN).

The MEOR process mechanism is:

1. Oil Degradation by Microorganisms
2. Biosurfactants in Microbial Metabolism
3. Emulsification
4. Altering Reservoir Physical Properties
5. Microscopic Mechanism

Planning in Conducting MEOR

The microbial flooding system includes activating material composition, slug injection, nutrient concentration, nutrient sizing and slug injection. The increase in recovery occurred after the growth period.

Referring to laboratory research and field tests in China, there are 8 main parameters for reservoir screening and evaluation for microbial flooding as follows (CNPC MEOR Screening criteria):

Table 1 – CNPC MEOR Parameters. *Haicheng She et al. (3)*

Parameter	Value Range	Optimum
Formation temperature (°C)	20-80	30-60
Crude viscosity (mPa·s)	10-500	30-150
Permeability (mD)	≥50	≥ 150
Porosity (%)	12-25	17-25
Brine salinity (g/L)	≥300	≥100
Wax content (%)	≥4	≥7
Water cut (%)	40-95	60-85
Total bacterial concentration in produced fluid (number/mL)	≥100	≥1000

Considering the results of that research, the parameters for the Shengli Oil Field test are as follows:

Table 2 – Shengli Oil Field MEOR Parameters. *Haicheng She et al. (3)*

Formation temperature(°C)	Permeability (mD)	Formation brine (pH)	Formation brine salinity (mg/L)	Dead oil viscosity at 50°C
≤80	≥50	6~8	≤150000	≤3000

Microbial flooding recovery field test in China showed an increase in oil recovery at 4.95% with 0.1 PV slug.

There are several types of microbes and their applications in MEOR as follows:

Table 3 – Types of Microbes and MEOR Applications (*McInerney MJ et al., 2002*), (*Harry Budiharjo et al (4)*)

Microbial Product	Example Microbes	Application in MEOR
Bio-mass	Biomass Bacillus, Leuconostoc, Xanthomonas	Selective plugging and wettability alteration
Surfactant	Acinetobacter, Arthrobacter, Bacillus, Pseudomonas	Emulsification and de-emulsification through reduction of IFT
Polymer	Bacillus, Brevibacterium, Leuconostoc, Xanthomonas	Injectivity profile and viscosity modification, selective plugging
Solvent	Clostridium, Zymomonas, Klebsiella	Rock dissolution for better permeability, oil viscosity reduction
Acids	Clostridium, Enterobacter, Mixed acidogens	Permeability increase, emulsification
Gasses	Clostridium, Enterobacter Methanobacterium	Increased pressure, oil swelling, IFT and viscosity reduction

Based on the pressure, the maximum pressure for live microbes is 7000 – 8000 psi, above that it will have a negative impact on microbial growth. Based on temperature, there are 3 types of microbes, namely Psychrophiles (<25°C), Mesophiles (25-45°C) and Thermopiles (45-60°C).

MEOR Implementation Worldwide

There are 17 countries that have implemented the MEOR besides Indonesia. This implementation is intended to overcome production problems, namely: formation damage; low oil relative permeability; trapped oil due to capillary forces; poor sweep efficiency channeling; unfavorable mobility ratio; low sweep efficiency; water or gas coning. Positive implementation results were found in 10 countries and negative results were found in 6 countries and 1 country for which there was no report *(I Lazar et al. (5)).*

MEOR in Indonesia.

MEOR has been tested and researched in Indonesia since 1992 at Pertamina EP in Prabumulih Field. There are several fields that have been tested by MEOR, including Prabumulih, Cepu (not specifically named), Ledok, Kawengan, Klamono, Bentayan, Mangunjaya and PT Chevron Pacific Indonesia in Balam South, Bangko and Minas Fields. There are at least 7 SPE papers that discuss MEOR technology in Indonesia. In this paper, we will discuss the implementation of MEOR in Cepu, Ledok, Bentayan and Mangunjaya.

MEOR in Cepu

MEOR has been implemented in 10 wells. Microbial selection is based on reservoir permeability, pressure and temperature. Clostridium sp. and Bacillus sp was chosen because it can grow in conditions of temperatures up to 230°F (110°C) and pressures up to 7000 psi. The lowest permeability in the 10 wells is 7 – 38 mD, while for the other 9 wells the permeability is categorized according to *Kalish et. Al, 1964* is a medium category that has a pore size of 4.5 – 5 µm. The width of the Clostridium sp. and Bacillus sp is 0.1 - 0.3 µm so it can be transported and grow in rock pores. Success analysis is in 2 ways, the first is the analysis from oil sample and the second is the analysis from production data before and after MEOR.

Table 4 – Pore size category and permeability range according to *Kalish et. Al, 1964 (Harry Budiharjo et al (4)*) as follows:

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

Table 5 – MEOR Screening by *Ahmed Eltayeb et al., 2013 (Harry Budiharjo et al (4))* as follows:

Factor	Limit	Optimum	Comment
Pressure (Psi)	Not Critical	-	Extremely high pressure are troublesome to non adapted bacteria
Temperature (°C)	<80	30 – 50	Depend on the microbe
Viscosity (CP)	>20	-	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 (ppm)	<10% NaCl<150000	-	-
Lithology	Not Critical	Carbonate	-
Depth (ft)	<7800	-	Depend on the corresponding temperature
Porosity (%)	>10	>10	Not limiting
Permeability (mD)	>50	>150	-
Oil Saturation (%)	-	>25	Successful trials with a low saturation was reported

In the analysis of oil and brine used 4 parameters, there are oil viscosity, API gravity, pour point and stability index (SI). The results of the analysis showed that there was a decrease in oil viscosity by 13% - 31.3% in 6 wells and a decrease in viscosity of less than 10% in 4 wells. There is an increase in API gravity of 1.5%-9.3% in 5 wells and an increase of 0.5%-0.9% in 5 wells. There was a pour point decrease of 3%-21% in 9 wells. SI analysis shows an increase in 10 wells, it shows that it could be make scale in production facilities which can reduce production.

In the analysis of production after 21 days MEOR shows an increasing production. The largest increasing production was 66% and the smallest increase in production was 8%. There are 2 wells that experienced a decrease in production indicating failure which was probably caused by the large stability index. The results of the SI analysis show an increase.

The comparison graph before and after MEOR is as follows *(Harry Budiharjo et al (4))*:

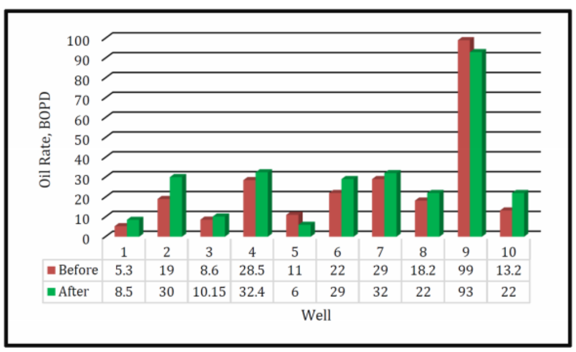

Figure 3 – The comparison graph before and after MEOR

MEOR in Ledok

In Ledok, huff and puff MEOR is implemented in the LDK-132 well. Prior to the field test, a lab test was conducted with the fluid taken from the well head and native core from the LDK-P1 well for comparison with the standard core (Classach) from Scotland. Core of LDK-P1 with a permeability of 140 mD. The microbes used were indigenous from LDK-132 enriched with Bacillus licheniformis and M4+. The results of the lab test test can increase the gain by 12.58%, reduce the permeability by 52.11%.

Table 6 – Coreflood Test Result with MEOR. *A. Yusuf et al (1)*

No.	Core Sample	Pore Vol. (cc)	Initial Water Saturation		Initial Oil Saturation		Oil Production Water Injection		Type Of Microbes	Shut In (days)	Oil Production Microbes Inject.		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	CLASSACH	13.73	4.03	29.33	9.70	70.67	5.93	61.13	LDK-132 + BL	16	0.80	8.25	21.22

Field test was conducted on July 8, 1999, there was an increasing production of 8.18 bopd on June 15, 1999. Investment of 3000 USD with income above cost of 926.4 USD for 4 weeks.

MEOR in Bentayan

Lab tests were carried out in wells BN-38 and BN-81. Screening based on a combination of Aladasani and Bryant methods. During the lab test, the number of bacteria during the incubation period was observed every 7 days using the Total Plate Count (TPC) method on Nutrient Agar (NA) media for aerobic facultative bacteria and Reinforced Clostridial Medium (RCM) for anaerobic bacteria. Optimum nutrient composition consists of molasses, nitrogen salt of the type $(NH4)_2PO4$ and NPK type phosphate salt for well BN-38. In contrast to BN-81, especially in the concentration of molasses. The composition after treatment was observed with GC/MS clearly to be a lighter composition. Heptane plus degraded more than 30%. Decreased viscosity to 43.68% in BN-38 and 47.83% in BN-81. The imbibition experiment showed RF 56% and optimum soaking for 7 days in BN-81.

Table 7 – Screening Method by Aladasani and Bryant . *(D. I. Astuti et al (2))* as follows:

Parameter	Reference	
	Aladasani (2012)	Bryant (1991)
API	12.0 – 33.0	>15
Viscosity (CP)	1.7 – 8900	-
Porosity (%)	12.0 – 28.0	-
Oil Saturation (%CP)	55 – 65	>25
Formation Type	Sandstone	-
Permeability (mD)	60 – 200	>50
Depth (ft)	1572 – 3464	<8000
Temperature (oF)	86 - 90	<170

Flow chart of the imbibition test for Well BN-81 is as follows:

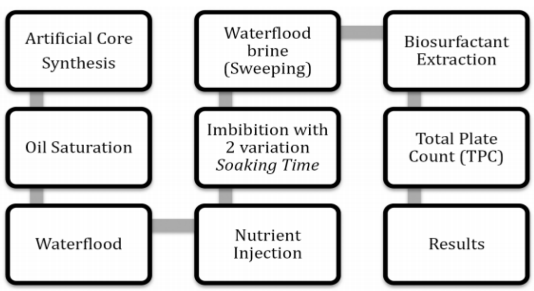

Figure 4 – Imbibition Flow Chart Analysis. *D. I. Astuti et al (2)*

The most optimum nutrient composition consisted of 7.16% w/v molasses, 0.3% w/v $(NH4)_2PO4$ and 0.26% w/v NPK.

In the pilot test with a gradually nutrient injection program of 500 bbls nutrient followed by 100 bbls post flush then a second nutrient injection of 1500 bbls nutrient followed by 100 bbls of post flush. After injection, soaking is done for 14 days. Then 2000 bbls post flush injection was performed and soaked again for 7 days. After 3 months of observation the production of aerobic microbial abundance increased by 1000-fold and anaerobes increased 10-fold. This abundance changes the physical and chemical conditions of oil and reduces oil viscosity by 24 percent and IFT by 47 percent. In both wells the water cut reduces from 99% to 92% and increases oil production by 1395 bbls. Economic calculations show Pay Out Time (POT) for 4 months and a production gain of 1750 bbls.

MEOR in Mangunjaya

Applied with the Huff and Puff method in the MJ-122 and MJ-125 wells. Reservoir parameter screening based on Aladasani and Bryant method. Screening on 5 wells, namely MJ-122, MJ-74, MJ-125, MJ-116, MJ-42. From that five wells, based on laboratory tests, the best results were MJ-122 and MJ-125. Monitoring was carried out for 6 months consisting of microbial population, composition analysis of oil production samples and production performance. Bacterial growth all of them was in the range of 2x103 CFU/mL – 5 x106 for 176 days in MJ-122 and more than 500x106 CFU/mL in MJ 125 for 122 days. After 3 months monitoring the biodegradation reached 34%. Field test results showed MJ-122 water content decreased at low production. MJ-125 experienced an increase in oil production by 20% with a decrease in water content at low and high production rates.

Huff and Puff field test MEOR process flow is as follows:

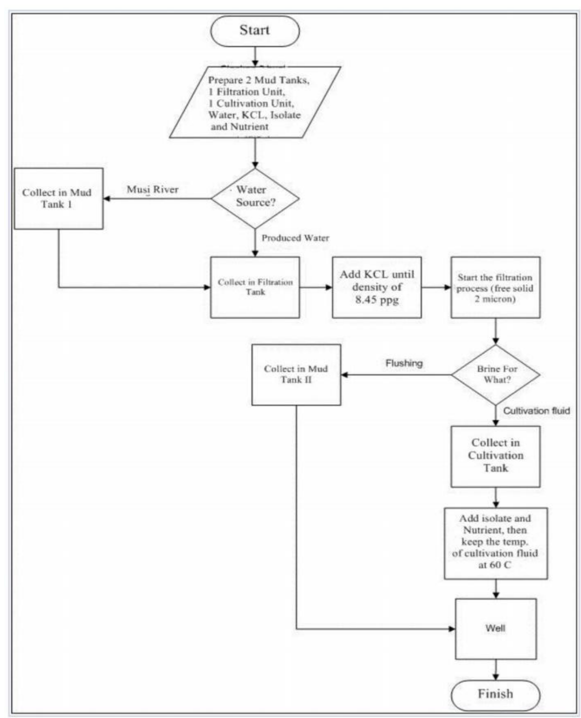

Figure 5 – Process Flow MEOR Injection. *T. Ariadji et al (9)*

Table 8 – The flow of fluid requirements (*T. Ariadji et al (9)*):

50 bbls	200 bbls	50 bbls	Soaking	200 bbls	200 bbls	Soaking	600 bbls	Soaking
Pre-flush (brine)	Inject MEOR (100 formation + 98 brine + 2 bbls oil)	Post Flush (brine)	7 days	Inject MEOR (100 formation + 98 brine + 2 bbls oil)	Post Flush after jobs (brine)	3 days	Post Flush after soaking 3 days (brine)	1 day

Discussion

Based on several references in the application of MEOR as mentioned above, it indicates that need a reservoir screening consisting of fluid, rock and reservoir conditions. Prior to implementation in the field, several tests were carried out in the laboratory consisting of testing the nutritional composition, microbial growth and coreflood. Usually it will be selected if the coreflood results show an increaseing gain of more than 10%. After testing in the laboratory is completed and getting the best nutritional formula, then proceed with implementation in the field. In Indonesia, the implementation in the field that has been done using huff and puff.

From several examples of implementation above, it is found that the implementation in Cepu resulted in an increase production by 8%-66%. The number of wells implemented is also at most 10 wells, while in Mangunjaya and Bentayan there are 2 production wells and Ledok 1 production well. MEOR implementation can also reduce water content, so that if gross production is also reduced, the nett production obtained is not so visible. The parameters of these success criteria must refer to good engineering practice based on the ability of the wells tested before MEOR is carried out. The effect of MEOR on the huff and puff system is usually up to 3 months after injection and soaking In order to maintain production, the huff and puff must be repeated.

Based on MEOR screening by Aladasani, Bryant, Ahmed Eltayeb and CNPC with parameters API Gravity and Temperature there are several oil fields in Indonesia may suitable to MEOR implementation.

Table 9 – The structure of oil fields in Indonesia that are suitable as initial MEOR candidates there are:

Oil Fields	^{o}API Oil at max 33^o	T Reservoir (^{o}F) at max 170^{o}F
Kenali Asam	18 - 21	115 - 138
Setiti	24 - 27	125 - 135
Ketaling Timur	20 - 31	119 - 149
Tempino	20 - 23	100 - 115
Bentayan	20	155
Mangunjaya	22 - 28	122
Ibul Tenggara	30 - 35	250 - 260
Dewa	16 - 35	250 - 260
Abab	22 - 30	220 - 230
Raja	22 - 34	250 - 260
Benakat Barat	19 - 35	130 - 180
Jirak	23 - 36	130 - 180
Talang Akar	30 - 35	130 - 180
Sopa	30 - 40	280 - 300
Ogan	25	168 - 200
Talang jimar	28	170 - 212
Tanjung Miring Barat	29	150 - 210
Tanjung Miring Timur	27	180 - 200
Kawengan	31 - 36	130 - 145
Ledok	26 - 42	130 - 145
Warukin	25 - 33	104 - 140
Klamono	19	140 - 158
Linda	18	167 - 183

Conclusion

1. MEOR has been implemented in several oil fields in Indonesia including Cepu, Ledok, Bentayan and Mangunjaya
2. The implementation in several fields was carried out by Huff and Puff and some managed to get a fairly good increase in production.
3. The length of time for the operation of MEOR huff and puff injection and soaking is relatively long, so it is necessary to select candidate wells through field screening and laboratory testing with many candidates and test variations.
4. Success criteria parameters should be determined prior to MEOR implementation based on good engineering practice and well production testing should be carried out to obtain optimum production figures before MEOR is carried out.
5. Based on the screening criteria, there are still many potential MEOR candidates in several fields in Indonesia.

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References

1. A. Yusuf, Sri Kadarwati, Nurkamelia, LEMIGAS, and Sumaryana, PERTAMINA, "Field Test of the Indigenous Microbes for Oil Recovery, Ledok Field, Central Java", Society of Petroleum Engineers, SPE 57309.
2. D.I. Astuti, T. Ariadji, P. Aditiawati, I. A. Purwasena, G. P. Persada, A. A. Ananggadipa, U. R. Dewi, D. D. Khendarsyah, and R. Rizki, Bandung Institute of Technology; M. H. Abqory and R. N. Ardianto, PT Pertamina EP, "A Comprehensive Preparation Study for Microbial Nutrient Injection of Microbial Enhanched Oil Recovery : Reservoir Screening and Laboratory Analysis – Case Study Bentayan Field", Society of Petroleum Engineers, SPE-186249-MS.
3. Haicheng She, School of Civil Engineering and Architecture, Xi'an University of Technology, Xi'an, 710048 Shaanxi, China; Debin Kong, Yiqiang Li, State Key Laboratory of Petroleum Resources and Prospecting, China University of Petroleum-Beijing, Beijing 102249, China; Zaiqiang Hu, School of Civil Engineering and Architecture, Xi'an University of Technology, Xi'an, 710048 Shaanxi, China; Hu Guo, School of Petroleum Engineering and Environment Engineering, Yan'an University, Yan'an, 716000 Shaanxi, China, "Recent Advance of Microbial Enhanced Oil Recovery(MEOR) in China", Hindawi, Geofluids Volume 2019, Article ID 1871392.
4. Harry Budiharjo, Nur Suhascaryo, Handika Agung Nugroho, and Benny Ariandy Saputra, Universitas Pembangunan Nasional Veteran Yogyakarta, "Optimizing Oil Recovery through Microbial Injection to Support the Increasing Demand for Oil in Indonesia", Society of Petroleum Engineers, SPE-186214-MS.
5. I. Lazar , I. G. Petrisor & T. F. Yen (2007), "Microbial Enhanced Oil Recovery (MEOR)", Petroleum Science and Technology, 25:11, 1353-1366, DOI: 10.1080/ 10916460701287714.
6. Lewis R Brown, Mississippi State University, Biological Sciences, "Microbial enhanced oil recovery (MEOR)", Science Direct, Elsevier.
7. Saikrishna Maudgalya, SPE, Anadarko Petroleum Corp., and Roy M. Knapp, SPE, and Michael J. McInerney, SPE, U. of Oklahoma, Norman, "Microbial Enhanced-Oil-Recovery Technologies: A Review of the Past, Present, and Future", Society of Petroleum Engineers, SPE 106978.
8. Steven L. Bryant, The University of Texas at Austin, and Thomas P. Lockhart, SPE, Enitecnologie, "Reservoir Engineering Analysis of Microbial Enhanced Oil Recovery", Society of Petroleum Engineers Inc, SPE 63229.
9. T. Ariadji, D. I. Astuti, P. Aditiawati, I. A. Purwasena, G. P. Persada, M. R. Soeparmono, N. H. Amirudin, A. A. Ananggadipa, and S. Y. Sasongko, Bandung Institute of Technology; M. H. Abqory and R. N. Ardianto, Pertamina EP; E. Subiantoro and G. H. Aditya, EMP Malacca Strait, "Microbial Huff and Puff Project at Mangunjaya Field Wells: The First in Indonesia Towards Successful MEOR Implementation", Society of Petroleum Engineers, SPE-186361-MS.
10. T. Ariadji, D. I. Astuti, N. Priharto, A. A. Ananggadipa, G. P. Persada, and E. Subiantoro, Bandung Institute of Technology; P. E. Erwanto and M. H. Abqory, PT Pertamina EP, "Field Implementation of Nutrient Huff and Puff in Bentayan Field, South Sumatera: Towards a Low-Cost EOR", Society of Petroleum Engineers, SPE-196536-MS.

Appendix

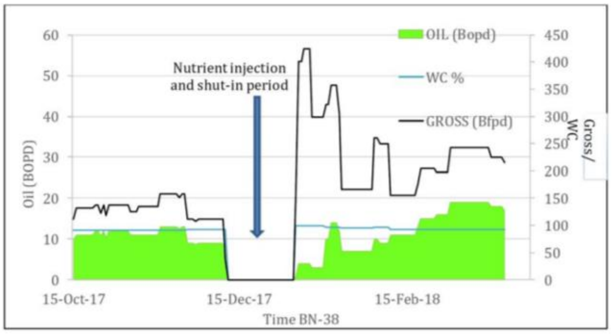

Figure 6 – MEOR Production Performance at well BN-38. *T. Ariadji et al (12)*

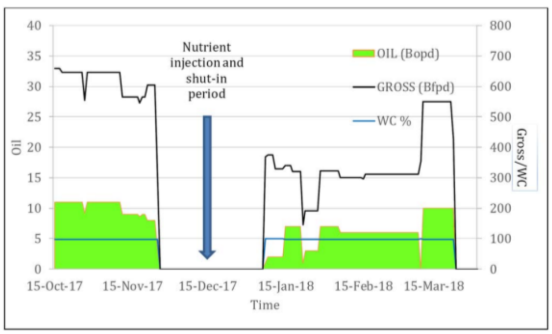

Figure 7 – MEOR Production Performance at well BN-81. *T. Ariadji et al (12)*

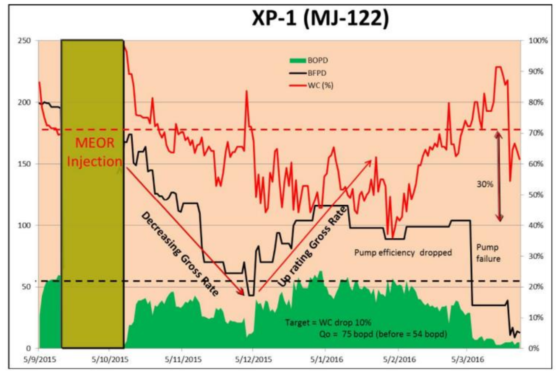

Figure 8 – MEOR production performance at well MJ-122. *T. Ariadji et al (11)*

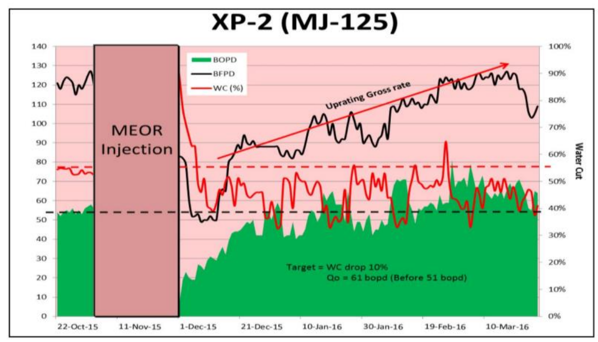

Figure 9 – MEOR Production Performance at well MJ-125. *T. Ariadji et al (11)*