PROCEEDINGS
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Vibroseismic Stimulation for Bacterial Core Flooding Simulation by Using Handil Oil Isolate *Geobacillus toebii* R-32639 and R-32653 to Artificial Core

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Abstract

This advanced research related to combination of MEOR (Microbial Enhanced Oil Recovery) and vibroseismic stimulation conducts laboratory scale simulation of indigenous bacterial injection into laboratory scale reservoir model by using artificial core. Previous study results two bacterial isolates from Handil Field, identified as *Geobacillus toebii* R-32639 and R-32653, and could increase recovery factor from 40% to 60%. This research aims to analyze the combination of bacterial injection with vibroseismic stimulation on the recovery factor. Bacterial isolates that used for injection is an 1:1 ratio mixed culture of *Geobacillus toebii* R-32639 and R-32653 with 10^6 cells/mL density. Artificial core permeability value that were used for bacterial injection is ranged from 5 mD to 200 mD and porosity ranges from 24% to 49%. Oil saturated artificial core that has been applied with waterflooding were then injected with bacteria and observed the recovery factor after incubation for 7 days at 55^0C. The results obtained combined with the incremental recovery factor from vibroseismic stimulation. Photomicrographs investigation by SEM (Scanning Electron Microscope) is performed to confirm the presence of bacteria in artificial core. Laboratory study resulted that waterflooding process yield a recovery factor between 14.3%-83.3%. Incubation for 7 days after bacterial injection on artificial core with permeability range of 5 mD-15 mD; 15 mD-50 mD; and 50 mD-200 mD are 13.7%-60%, 13.1%-45.7%, and 22.6%-86.6% respectively. Vibroseismic stimulation with 15 Hz frequency and waterflooding on artificial cores from reached 18.6% of additional recovery factor. Artificial core porosity and permeability values increased by 27.4% and 34.5%. Injected bacteria can attach and survive on artificial cores, indicated by the presence of bacteria on the SEM photomicrograph.

Introduction

The importance of Enhanced Oil Recovery (EOR) application in Indonesia has came to higher level, due to the declining of oil production. Microbial Enhanced Oil Recovery (MEOR) offers alternative method to increase oil production from existing wells with low environmental impact. Previous studies related with MEOR resulted that Handil Field oil sample two dominant bacterial isolate which were *Geobacillus toebii* R-32639 and *Geobacillus toebii* R-32653 (Nurzara, 2011). These bacterial isolate are hydrocarbonoclastic microorganism that has the abilities to alter physical properties of artificial core by increasing its porosity and permeability. Bacterial core flooding within artificial core with 7 days soaking time resulted incremental recovery factor between 40-60% (Priharto, 2009). Combination of vibroseismic method and bacterial core flooding could be used for EOR. Vibroseismic method is an alternative EOR method that could stimulate oil and gas segregation, increase rock porosity and permeability, and decrease the saturated oil residue (S_{or}) (Ariadji, 2005). Elastic wave that applied in vibroseismic stimulation could alter trapped oil in smaller pores and reduce the interfacial tension (IFT) and ease extraction of oil droplets from artificial core. Previous study of vibroseismic stimulation by 15 Hz combined with waterflooding resulted 8.3% of incremental recovery factor after 14 days of incubation at 100-300 mD permeability interval artificial core (Utomo, 2010).

Data and Method

Bacterial Acclimatization

Geobacillus toebii R-32369 and R-32653 isolate with 10^6 CFU/mL density was inoculated by concentration of 10% (v/v) in recovery medium that contains 2% (v/v) of molasses, 2% (v/v) of oil, and 0.1 % (w/v) of urea in brine water as a mixed culture. Mixed culture was incubated at 55^0C with 100 rpm rotary shaker for 72 hours.

Artificial Core Preparation

Artificial core was composed by the mixture of various mesh size of quartz sand, 10% (w/w) cement, and water. Mixture was homogenized and inserted in PVC pipe with 1 inch of diameter and 2 inch of length. Constant pressure was applied until mixture became compact then dried for 3 days. Formed artificial core were pulled out from PVC pipe with cub motor.

Porosity and Permeability Measurement

Artificial core dry weight was measured then vacuumed for 4-5 hours to extract the trapped air within the rock pores and then soaked with brine water. Porosity were measured were determined by comparing pore volume (PV) from brine-soaked core with bulk volume (BV). Permeability were measured by using Hassler™ Permeameter with 22.5

cP of paraffin as injected fluid, 50 psi of injection pressure, and 10 psi of overburden pressure.

Oil Injection and Waterflooding

Oil was injected into brine saturated artificial core by using Hassler™ Core Holder by 100 psi overburden pressure, 0.8 cc/min injection rate, and 55^0 C injection temperature. Saturated oil residue (S_{or}) value was calculated and then injected by brine water (waterflooding) by 100 psi overburden pressure and 0.8 cc/min injection rate.

Bacterial Core Flooding

Core was injected with mixed culture of *Geobacillus toebii* R-32369 and R-32635 by 1:1 ratio (Purwasena, 2006). Injected volume was 0.25 PV, 0.8 cc/min of injection rate, and 100 psi overburden pressure. Injected artificial core were then soaked in brine water for 7 days at 55^0C temperature. Volume of extracted oil from artificial core was measured.

Vibroseismic Stimulation

Oscilloscope was used to determine circular wave that used for vibroseismic stimulation. Vibroseismic apparatus was used to apply stimulation to artificial core. The optimum wave frequency was 15 Hz and 55^0C of temperature for vibroseismic stimulation (Sitompul, 2008).

Artificial Core Preparation for SEM (Scanning Electron Microscopy)

Core sample was prepared with fixation by 2.5% (v/v) glutaraldehyde in phosphate buffer for 24 hours then rinsed with serial concentration of acetone (25%, 50%, 75%, 100%) every 15 minutes. Fixated core sample was incubated for 24 hours and dried. Sample were prepared by dimension of 1 x 1 x 0.5 cm to be analyzed for SEM examination.

Result and Discussion

Bacterial Acclimatization
Mixed culture of *Geobacillus toebii* R-32369 and R-32653 was incubated for 12 hours with 1:1 ratio. Figure 1 showed the highest growth rate of *Geobacillus toebii* R-32369 and Figure 2 illustrated the highest growth rate of *Geobacillus toebii* R-32653 (Purwasena, 2006)

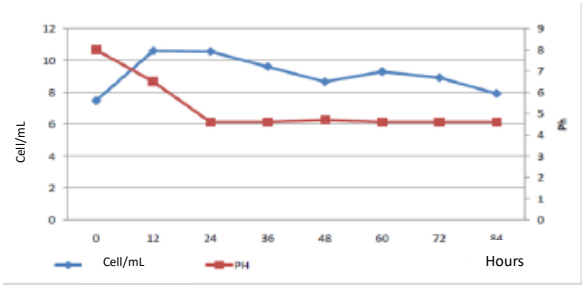

Figure 1: *Geobacillus toebii* R-32369 Growth Curve

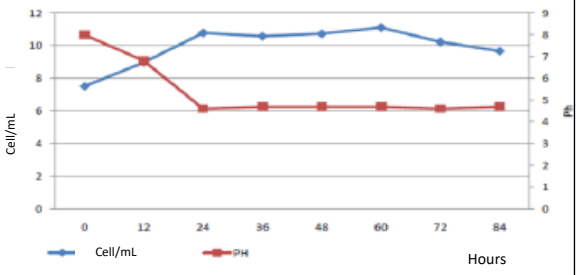

Figure 2: *Geobacillus toebii* R-32635 Growth Curve

Viability study resulted that each isolate grew after 72 hours in Nutrient Agar Plate. Each isolate was scaled up to 500 mL in recovery medium then mixed until reach 1 L total volume of mixed culture of *Geobacillus toebii* R-32369 and R-32635.

Artificial Core Preparation and Parameter Measurement

There was three different method of this experiment for artificial cores: negative control (without waterflooding), bacterial core flooding, and vibroseismic stimulation. Rock properties measurement of artificial cores resulted the interval value of porosity ranged from 24% to 49% and permeability ranged from 5 mD to 200 mD. Permeability interval of artificial core were specified for bacterial core flooding (5-15 mD, 15-50 mD, 50-200 mD).

Oil Injection and Waterflooding

Oil injection of artificial cores for three permeability interval illustrated in Figure 3, resulted the value of saturated oil residue (S_{or}) ranged from 5% to 90%. Variation of S_{or} depends on different value of core porosity and permeability (Peters, 2007). Particular value of interfacial tension (IFT) between oil and water in each core also determine the various S_{or} value (Ahmad, 2001).

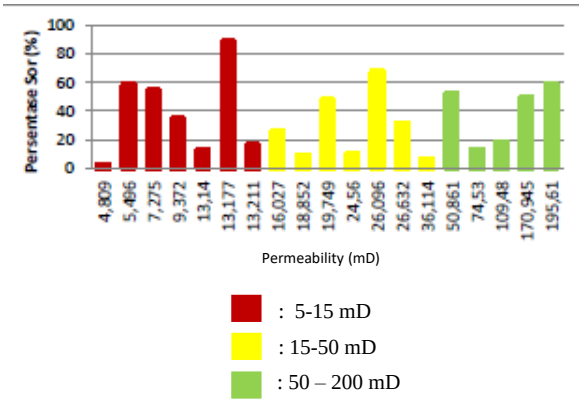

Figure 3: S_{or} Value from Oil Injection

Oil saturated artificial cores was injected with brine water (waterflooding), yields recovery factor (%RF) ranging from 14.3 – 88.3% for each permeability interval as illustrated in Figure 4.

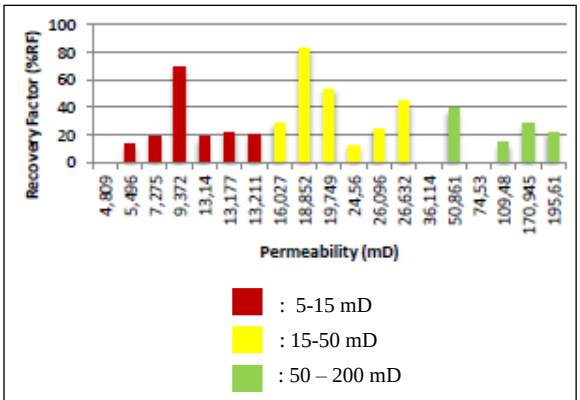

Figure 4: Recovery Factor (%RF) Value of Waterflooding

Variation of recovery factor (%RF) for each core was determined by waterflooding effectivity that depends on permeability and sweep efficiency (vertical and aerial), and displacement efficiency.

Bacterial Core Flooding

Cumulative recovery factor (%RF) of artificial core were then calculated after 7 days of soaking in brine water. Obtained recovery factor (%RF) of each permeability interval 5- 15 mD, 15-5- mD, and 50-200 mD were 13.7-60%, 13.1-45.7%, and 22.6-86.8% respectively, as illustrated in Figure 5.

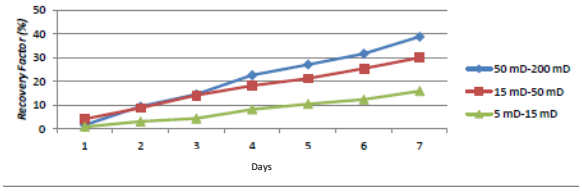

Figure 5: Cumulative Recovery Factor after Bacterial Core Flooding

Permeability range of 50-200 mD resulted the most recovery factor (%RF) by 22.6-86.8%, which caused by less viscous of oil that resulted more oil that can be swept from artificial core. Decreased of oil viscosity resulted from the effect of produced metabolites from injected bacteria (Lazar, 2007)

Vibroseismic Stimulation

Vibroseismic was stimulated by using 15 Hz frequency to artificial core after bacterial core flooding. Permeability value of artificial core that stimulated by vibroseismic was 13,221 mD; 16,027 mD, 26,632 mD; 74,53 mD; and 109,48, which has remaining trapped oil after bacterial core flooding that has S_{or} value lower than 30%. Figure 6 illustrated the cumulative recovery factor (%RF) after waterflooding, bacterial core flooding, and vibroseismic stimulation in particular artificial cores. The highest incremental recovery factor (%RF) from vibroseismic stimulation was 18.6% at 109.48 mD artificial core.

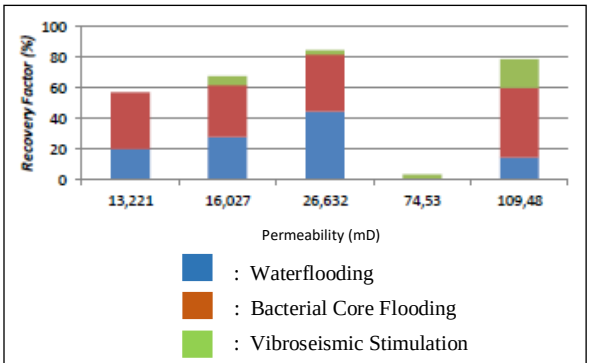

Figure 6: Cumulative Recovery Factor after Waterflooding, Bacterial Core Flooding, and Vibroseismic Stimulation

Effectivity of vibroseismic stimulation is depends on permeability. Higher permeability resulted higher gain of incremental recovery factor (%RF) (Sitompul, 2008). Vibroseismic stimulation could alter the surface roughness that caused instability between pores and fluid, resulting the ease of oil droplets in pores to be extracted.

SEM (Scanning Electron Microscopy) Examination

SEM (Scanning Electron Microscopy) photomicrograph of 109.48 mD artificial core after bacterial core flooding and vibroseismic stimulation showed the presence of rod-shaped bacteria inside the artificial core as illustrated in Figure 7. The lack of bacterial colony that attached in artificial core was caused by vibroseismic stimulation that disperse the bacterial colony.

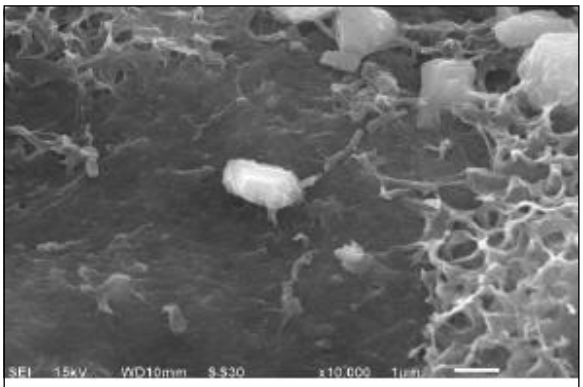

Figure 7: SEM Photomicrograph of 109.48 mD Artifical Cores

Additional Energy Dispersive X-ray (EDX) spectroscopy of artificial core resulted that carbon (C) was the highest components of by 22.09%. Carbon is the major compounds of bacterial cells (Madigan, 2008).

Conclusion

Artificial core with 24-49% range of porosity and 5-200 mD resulted 5-90% of saturated oil residue (S_{or}) after oil injection. Waterflooding resulted 14.3-88.3% range of recovery factor. Bacterial core flooding resulted recovery factor (%RF) for permeability interval 5- 15 mD, 15-5- mD, and 50-200 mD were 13.7-60%, 13.1-45.7%, and 22.6-86.8% respectively. The highest incremental recovery factor (%RF) from vibroseismic stimulation was 18.6% at 109.48 mD artificial core. SEM-EDX examination confirms the presence of bacteria inside the acritical core after bacterial core flooding and vibroseismic stimulation.

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