

THE POTENTIAL OF INDIGENOUS BACTERIA TO INCREASE POROSITY-PERMEABILITY OF RESERVOIR ROCK: A PRELIMINARY STUDY

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ABSTRACT: Oil content extraction from the rock pores can be very complicated due to the high viscosity of petroleum oil and low degree of reservoir rock porosity as well as its permeability. A research had been carried out with the use of mix populations of indigenous bacteria isolated from formation water (fw), well-site sludge (ws) and well mud (wd). Limestones was used as samples. This cores were soaked for 2 (two) weeks in 55⁰C, a media contained of 1% molasse dissolved in sterilized formation water and 20% crude oil as covering. During the research, there was a change in the pH environment from neutral to acid. Acid production from the reaction result with carbonate in the solution will lower pH of the water that was produced. Changing value of porosity (%) that was injected by bacteria from fw, ws, and wd, increases respectively 23.22, 68.29, 14.89, and changing value of permeability (%) respectively 56.28, 137.83, 35.77. Even though on average there were an increase in value of porosity and permeability, there were also a decrease in the value of porosity and permeability of a few of the limestones samples. Inoculum bacteria from the pollution around the oil well are much more adaptive and give more carbonate dissolving reaction than the other actions. MEOR (microbial enhanced oil recovery) technique is really dependent on the growth of the microbes in site, and the development of the secondary metabolit products that can change the porosity and permeability of the reservoir limestones.

Keywords: Indigenous bacteria, Limestones, Oil recovery, Porosity, Permeability.

1. INTRODUCTION

Needs of petroleum fuel has greatly risen in recent decades, while new oil reserves are increasingly difficult to obtain. Given the important role and nature of petroleum oil that can not be renewed, the efforts to optimize oil extraction continues to be improved. Exploitation of petroleum oil in early stage (primary recovery) generally relies on the driving force derived from reservoir pressure. When this phase ends, in line with the reduced driving force, further extraction techniques are then applied to the reservoir, including thermal injection, chemical injection, solvent injection (solvent flooding), as well as mixed injection (miscible process). The main purpose of all these techniques is to mobilize the remaining oil to the surface. Current exploitation techniques are capable to lift only about 30% of remaining oil to the surface. The rest remains in the pores of reservoir rock [1]. Oil content extraction from the rock pores can be very complicated due to the high viscosity of petroleum oil and low degree of reservoir rock porosity as well as its permeability.

MEOR is one of the techniques used to exploit petroleum oil, developed since 1950s. It represents advanced oil recovery attempt by utilizing the ability of bacteria to produce secondary metabolites such as fatty acids, gases, surfactants, and biopolymers. MEOR technique begins by injecting bacteria into the reservoir, followed by pursuing formations of bacterial growth. Principally, MEOR is highly dependent on the growth of in situ bacteria and the production of secondary metabolites. Metabolic process basically results in the organism growth and development. However, not all of its products are consumable for growth and development. Residuals of metabolism in the form of secondary metabolites are excreted from the cell to the surrounding environment. Direct utilization of these secondary metabolites can alter the porosity and permeability of reservoir rock, potentially enhancing oil recovery process from the rock pores.

Basically, every type of rock can act as a reservoir rock as long as it has the ability to hold and to release petroleum oil. Thus, reservoir rock has to have porosity as the retention capability and also permeability as the discharging capability of

petroleum oil. Porosity determines the amount of liquid contained, whereas permeability determines the amount of liquid yielded [2]. A permeable rock will be considered porous with interconnected pores. Contrarily, a porous rock is not necessarily permeable because of the disconnected pores. Porosity does not depend on the particle size, while permeability is a direct function of the grain size.

This research aims to exploit the potential of indigenous bacteria isolated from the reservoir environment to increase the porosity and permeability of carbonate formation in reservoir rock.

2. MATERIALS AND METHODS

2.1 Preparation of Indigenous Bacteria and Bacterial Penetration into the Reservoir

Indigenous bacteria were isolated from three materials consisting of formation water, waste around oil wells, and used drilling sludge. Bacterial isolates were injected into the sample carbonate rock reservoir containing pure carbonate (100% limestone) according to Vance diagram (1950)[3], [4]. The rocks were formed into a cylinder with a diameter of 2.5 cm and a length of 3 cm, then were cleaned and its initial porosity and permeability were measured. The crude oil used in this study was classified as paraffin or low-density oil category. Sampling were performed at the beginning and the end of the treatment for 14 days to count the number of bacteria, porosity value, and permeability value of the rock sample. Rock samples that have been cleaned were wrapped in aluminium foil and were sterilized in an oven at 100°C for an hour to measure the initial porosity and permeability. After cooling down, the rock samples were aseptically inserted using large tweezers into erlenmeyers containing treatment media before the inoculation. Each erlenmeyer containing rock sample was stored in an incubator at 55°C for 14 days. Agitation was carried out using a shaker incubator at 120 rpm for 30 minutes, everyday during the experiment. Dilution plate method was chosen for bacterial count.

2.2 Porosity Measurement

Porosity is the ratio of pore volume (total medium/rock volume minus matrix volume/grain volume) to the total volume of rock. Porosity is usually expressed in percent (%), calculated as follows [4]

$$\phi = \frac{(\text{total volume} - \text{volume of grains})}{\text{Total volume}} \times 100\% \quad (1)$$

An instrument called Helse Gauge Porosimeter was used to measure porosity of the rock samples. The working principle is based on Boyle's law: at constant temperature, the product of pressure and volume of an object will be constant as well. This device was connected to a computer software called autoporosimeter. Helium gas was used to fill the pores of rock samples, considering that helium molecules are tiny enough to penetrate the smallest pore, helium atomic mass is low (high diffusion rate), and helium adsorption rate at the rock surface is also low and insignificant.

After 48 hours in the oven, the length and diameter of the samples were then measured. Turn on the autoporosimeter, then insert a disc of the same size with the sample diameter into the Helse tube and seal the tube. The computer will record the data of the correction disc. Remove the disc and replace it with a sample. Keep the space left inside the Helse tube to be minimum by adding the correction disc. Type the number and dry weight data of the sample, together with the number of the inserted correction disc into the computer. The computation result will then display GV (grain volume) and CD (core density) data. These are needed to calculate BV (bulk volume) = $A \times l$; PV (pore volume) = $BV - GV$; Porosity is then determined by the equation below:

$$\phi = (PV/BV) \times 100\% \quad (2)$$

2.3 Permeability measurement

Permeability is a property of reservoir rock to be able to convey liquid matter through the interconnected pores without damaging the rock structure or particles. Based on Darcy's law, permeability can be formulated as follows [5]

$$q = - (k A dp) / (\mu f dl) \quad (3)$$

According to the API code 27, a porous medium has a value of permeability (k) of 1 Darcy if a single-phase liquid with a viscosity (μ) equals to 1 centiPoise flows at a velocity (q) of 1 cm per second through a cross-section (A) covering an area of 1 cm² with a hydraulic gradient (dp/dl) of 1 atm (76.0 cm Hg) per cm² and if the liquid entirely occupies the medium. Negative sign in the equation above shows an opposite flow to the hydraulic gradient. Unit of permeability is often expressed in miliDarcy (mD) due to its common value of only between 5–1000 mD (1 mD = 0.001 D).

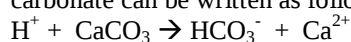
Permeability of rock samples were measured using an instrument called gas permeameter. Its principle is also based on Darcy's law, stating that the fluid rate in porous media is directly

proportional to the pressure force driving the fluid and rock permeability, but inversely proportional to fluid viscosity. Data obtained from this device are orifice flowrate value (Or = orifice), height of water column (W = orifice water), and C value whose magnitude depends on the type of applied pressure. The pressure value can be read at the center water manometer which needs to be corrected later due to the friction loss. This number is then converted to C value using Water to Water permeability C chart. Samples of limestone were estimated to have low permeability that require measurement at high pressure. In this case, C value was constant at 4. Permeability (K_a) can be calculated by using orifice flowrate data (Or), height of water column (W), C value, the average length (L), and total area of the cross-section (A), based on following equation:

$$K_a = \frac{Or \times W \times C \times L}{200 \times A} \times \text{correction factor to temperature} \quad (4)$$

3. RESULTS AND DISCUSSION

The use of bacteria in carbonate formations is highly dependent on the presence of carbonate and acid production of fermented carbohydrates that will react with the carbonate. The influence of gas production is considered very small and insignificant to the acquisition of oil residue. The reaction occurs between acid of fermented carbohydrates and the rock matrix in the form of carbonate can be written as follows:



Results from porosity and permeability measurement of limestone samples can be seen in Figure 1. Outcomes of the three treatments generally indicate an increase in the porosity and permeability value.

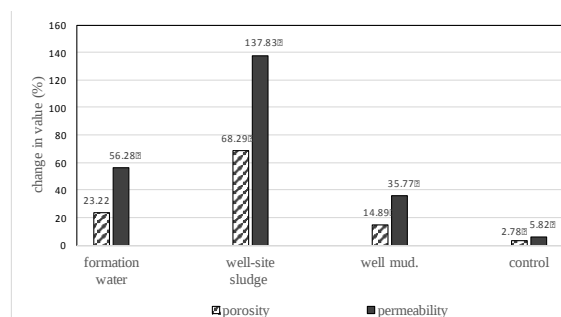


Fig 1. The test results of the porosity and permeability of the limestone samples

During the first treatment using formation water inoculum, porosity raised between 1.35%–52.15% with an average of 23.22% and

permeability increased between 21.8%–94.50% with an average of 56.28%. The second treatment using bacterial inoculum taken from waste around the oil wells shows an increased porosity of 13.71%–94.10% with an average of 68.29% and increased permeability of 89.35%–188.68% with an average of 137.83%. The third treatment by drilling mud inoculum increased the porosity value between 0.60%–26.67% with an average of 14.39% and permeability between 5.91%–98.21% with an average of 35.77%. Acid production is the basic mechanism for MEOR technique and is also a specific target for the implementation of the carbonate-based reservoir. The reaction expected to occur between the products of carbohydrate fermentation by bacteria and the rock matrix can be written as follows: $H^+ + CaCO_3 \rightarrow HCO_3^- + Ca^{2+}$

Acidic compounds yielded from this reaction will lower the pH of the produced water. Acid production is expected to disperse in the reservoir on a broad scale, then dissolve and shed the rock matrix so that it can increase the porosity and permeability of the rock.

For the control samples, porosity value changed irregularly between -5.31% (down) to 4.95% (up) with an average of 2.78%, whereas permeability entirely decreased between 2.15%–8.55% with an average of 5.82%. These controls were not injected with bacteria. Irregular porosity change were mostly caused by the agitation process on shaker incubator (it cracked the samples and sank most of the matrix). Several injected samples also experienced this irregular change, but it was mostly caused by bacterial activity. The difference can be seen in the declining permeability value of controls which were caused by the presence of carbonate matrix sediment and also sediment of other substances contained in formation water that blocked the cleft off.

Bacterial count from the first day (day 0) to day 14 decreased immensely. It may be caused by the shifting of environmental pH from neutral to acidic condition. Acid production induced by carbonate reaction in the solution will lower the pH of produced water. In this study, environmental pH in all treatments dropped from neutral point (7.0) to acidic range (5.2 ± 0.5). This sharp decline in pH can interfere with bacterial metabolism. According to [6], at 5.0–5.5 pH range, metabolic process of certain type of bacteria may be interrupted.

The increase in porosity and permeability obtained in this study were not significant due to the very small permeability value of the rock samples, whereas an effective bacterial EOR typically comes in an average permeability of 150 mD. Nevertheless, considering that the

permeability have risen indeed, bacterial penetration into the rock samples may have been taken place, enabling carbonate dissolution by acidic compounds generated from bacterial fermentation. The results show that the treatment using bacterial inoculum from waste around the oil wells has better ability to increase porosity and permeability compared to the other two.

Bacterial population monitoring portrays a decrease of bacterial count in each treatment. For the treatment using waste inoculum, the population tended to approach a constant growth. Taking into account of the bacteria properties to clog and to reduce porosity and permeability, it can be seen that the decrease of porosity value by this treatment was much larger than the other two. It can be concluded that in this study, indigenous bacteria played a decent role in reducing the porosity and permeability.

Presence of red bacterial colonies (due to the colour of safranin) is depicted in the photograph of the rock structure after the treatment. There were no sign of it in the control samples, bringing clear pictures of the rock-forming material in the form of cavities/pores between grains, filled by oil. On the other hand, it can be seen in the treated samples that visible colonies of bacteria were able to penetrate into the rock pores, either forming a thin layer attached to the grains or even lumps that clogged the pores.

In the water injection technique, these blockages can be exploited to clog high permeability formations so that the water flow can be redirected and focused to sweep out the remaining oil trapped in the low permeability formations. This way, sweeping efficiency can be optimized. In this technique (known as selected/targeted cloggings), the condition of bacteria greatly affects its ability to penetrate. The bacteria that are in a state of hunger has a smaller size than normal bacteria in the vegetative state, so it can penetrate deeper into the reservoir rock formations [7]. The bacteria growth and reproduction itself will subsequently serve as the agent of the formations clogging. The effectiveness of this technique is highly dependent on the accuracy of the bacteria placement/seeding in the specified high permeability formations and the impact inflicted by the cloggings established later.

Reference [8] estimated that the vertical movement of water in the aquifer affects the ability of bacterial penetration. Although the penetration of bacteria from the surface takes many years, but as long as the flow of water in the aquifer contains organic carbons (particularly of rocks passed by), the penetration of the slow-developed colonies can keep going. Based upon the properties of its permeability, Jaranyl in [1] recommends that the

use of microorganism in EOR should only be introduced to rock formations having permeability value of larger than 60 MD. MEOR technique, according to [1], will be effective on moderate (150–300 MD) to high permeability rocks (400–700 MD). However, strains studied by Myers and McCready apparently were able to penetrate 'Mississippian limestone' and 'late Mesozoic sandstone' formations with permeability value of less than 0.1 MD.

4. CONCLUSION

Bacterial isolates that have been collected from formation water, well-site sludge, and well mud, then have been injected into the reservoir carbonate rock, were able to improve rock porosity (%) to 23.22, 68.29, and 14.89 respectively, also rock permeability (%) to 56.28, 137.83, and 35.77 respectively, due to the dissolution of carbonate rock matrix by acidic substances generated from bacterial metabolism. Bacterial inoculum derived from the well-site sludge was more adaptive and gave a greater carbonate dissolution effect compared to the formation water and mud well bacteria. Bacterial isolates collected from the well-site sludge was also found to be a better clogging agent.

5. REFERENCES

- [1] Shibulal, B., Al-Bahry SN, Al-Wahaibi YM, Abdulkader E. Elshafie, Ali S. Al-Bemani, and Sanket J. Joshi, "Microbial Enhanced Heavy Oil Recovery by the Aid of Inhabitant Spore-Forming Bacteria: An Insight Review", Hindawi Publishing Corporation, The Scientific World Journal, Vol. 2014, 2014, pp. 1-13
- [2] K. Fujiwara, Y. Sugai, N. Yazawa, K. Ohno, C.X. Hong, and H. Enomoto, "Biotechnological approach for development of microbial enhanced oil recovery technique", Studies in Surface Science and Catalysis, Vol. 151, 2004, pp. 405–445,
- [3] Vandecasteele JP, "Petroleum Microbiology: Concepts, Environmental Implications, Industrial Applications", Translated by Jones, T. France : Editions Technic, 2008.
- [4] Amiyy, J.W., D.M. Base, Jr., & R.L. Whitting, "Petroleum Reservoir Engineering: Physical Properties", New York : McGraw-Hill, 1982.
- [5] Monicard, R.P, "Properties of Reservoir Rocks : Core Analysis", Houston: Gulf Publ. Co., 1980.

- [6] Latha, R. and R. Kalaivani, Bacterial, "Degradation of Crude Oil by Gravimetric Analysis", *Advances in Applied Science Research*, Vol. 3, 2012, pp.2789-2795.
- [7] R. Al-Hattali, H. Al-Sulaimani, Y. Al-Wahaibi, "Microbial biomass for improving sweep efficiency in fractured carbonate reservoir using date molasses as renewable feed substrate", *Proceedings of the SPE Annual Technical Conference and Exhibition*, San Antonio, Tex, USA, 2012.
- [8] H. Suthar, K. Hingurao, A. Desai, and A. Nerurkar, "Evaluation of bioemulsifier mediated microbial enhanced oil recovery using sand pack column", *Journal of Microbiological Methods*. Vol. 75(2), 2008, pp. 225–230.
- [9] Ollivier, B, "Petroleum Microbiology", New York: American Society of Microbiology Press, 2005.

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