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"Natural Resources and Infrastructure Development for National Sovereignty"

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Ijen Sulte Hotel Malang
September 25 - 28, 2017

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"Natural Resources and Infrastructure Development for National Sovereignty"

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Jl. Prof. Dr. Supomo SH. No. 231
Jakarta Selatan 12870
Telepon: (62-21) 83702848
Fax: (62-21) 83702848

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JOINT CONVENTION MALANG 2017

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PREFACE

7th Joint Convention & Exhibition Malang (JCM 2017) has been jointly hosted by Indonesian Association of Geophysicists (HAGI), Indonesian Association of Geologists (IAGI), the Indonesian Association of Petroleoum Facility (IAFMI) and the Indonesian Association of Petroleum Engineer (IATMI). This is Indonesia's largest event devoted to the geoscientists and engineers, and it will give participants a platform to exchange ideas, discover novel opportunities, reacquaint with colleagues, meet new friends, and broaden their knowledge.

The theme of the convention is *Natural Resources & Infrastructure Development for National Sovereignty*. The slump in oil price and mining commodities to their lowest level in a decade is the challenges for geoscientists, engineers and other industry professionals gather at this event to plan their E&P business program and share their knowledge. The main theme covering two main topics, i.e. energy and infrastructures, that have dependency in supporting economic growth strategy for national sovereignty.

The proceedings may contain all papers presented in the JCM 2017, covering various topics including:

1. Natural Mineral, Coal, and Energy Geothermal Resources Management
2. Environtmental Issues and Hazard Mitigation
3. Geodinamics, Seismology, Petrology and Volcanology
4. Sediment and Stratigraphy
5. Geology, Geophysics, Geochemistry Methods, Technology and Application
6. Infrastructure, Engineering Geology and Geophysics, Hydrogeology, Oceanography
7. Petroleum Engineering, Technology and Application
8. Petroleum Geoscience
9. Unconventional and Renewable Energy
10. Deepwater, Production Facilities Oil and Gas Optimization, Decommissioning
11. Business Development
12. Geotourism and Others.

The papers are written by experts from various background including geological, geophysical, petroleum, mining and infrastructural community. It will broadly cover all disciplines of geoscience and engineering from fundamental research to "blue sky" applications of E&P activities.

On behalf of IAGI, HAGI, IAFMI and IATMI, we would like to thank all authors, paper reviewers and editorial board for providing the support and feedback necessary to find, develop, and publish material of such consistent high quality. I also would like to extend my thanks to all sponsor from industry, universities and government for their contributions and involvements. We highly appreciate our readers' feedback, so please share your ideas and thoughts with us.

Fatrial Bahesti – Chairman of JCM 2017

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JOINT CONVENTION MALANG 2017, HAGI – IAGI – IAFMI- IATMI (JCM 2017)
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Increasing Waterflood Recovery Efficiency Through Microbial Selective Plugging

Dr. Ir. Harry Budiharjo, M.T[1], Handika A. Nugroho[1] and Benny A. Saputra[1]
[1]UPN "Veteran" Yogyakarta

Abstract

Waterflooding is one of the improve oil recovery method that is injecting water to the reservoir through the injection well in purpose to push the oil out to the production well and increase the oil recovery. But because of the rock porosity and permeability heterogeneity of the reservoir make the water tends to flow to the high porosity and high permeability in the reservoir rock, so the waterflooding won't sweep the oil in the lower porosity and permeability, and left it behind. This condition can cause the water breakthrough and water channeling problem where the water rate production will be higher than the oil rate production.

The microbial selective plugging is a method of plugging high pore rock uses microbial or microbial metabolic product. The purpose of Microbial Selective Plugging is to increase the efficiency of waterflooding by plugging the high permeability zones and directing injected water into zones of the reservoir that have not been taking water (Lower Permeability Zone). And the water injection can push the oil in lower permeability zone out of the reservoir.

In 2009, the microbial selective plugging had been observed by Suthar and his team from Microbiology and Biotechnology Department Centre, India. The *Bacillus licheniformis TT33* was used as the bacteria, because the bacteria is facultative anaerobic, halotolerant, thermotolerant, and bio-film forming microorganism. *Bacillus licheniformis TT33* can also produce Exopolymeric Substances and bio-surfactant. The selective plugging of *Bacillus licheniformis TT33* was analyzed using sand pack column which has saturated with 80±2,9% oil, and the rest with brine. And after the brine flooding, there was 46,9±2,7% unrecoverable oil, and the amount of the unrecoverable oil which had been recovered by *Bacillus licheniformis TT33* was 27,7±3,5%.

Keywords: *Waterflood, Microbial Enhanced Oil Recovery, Selective plugging, Bacillus licheniformis*

Introduction

The one of improve oil recovery method is waterflooding that injecting water through the injection well to the reservoir to push the oil out through the production well, A\and waterflooding is the most widely used fluid injection process in world. It has been recognized since 1880 that injecting water into an oil-bearing formation has the potential to improve oil recovery. However, waterflooding hasn't field experience application until the 1930s when several injection projects were initiated, and it was not until the early 1950s that the current boom in waterflooding began. (James T. Smith & William M. Cobb, 1997).

Reservoir rock consist of variations of permeability, it gives a negative effect to the waterflooding. Because of the variations of the reservoir rock permeability, water injection flows through the thief permeability zone (fracture zone or high permeability zone) and leaving oil in the low permeability zone, or called as zones unrecovered. This condition can be indicated as water breakthrough and water channeling. Water injection tends to flow through the thief zone because it has higher permeability, so the oil saturation in the thief zone will be depleted sooner than in the less permeability zone. The thief zone will transmit the water injection in a faster rate because oil saturation is reduced and the effective permeability to water is increased, so the oil in the thief zone will be depleted but it will continue to transmit water injection to production well during the waterflood (Thomas M. Garland, 1966). And finally, the large producing volume of water injection will decreasing oil recovery efficiency of the waterflooding operation.

The one of the method to handle this problem is selective plugging. Selective Plugging will divert the water injection from the thief zone to the less permeability rock by plug the thief zone with the plugging agent. Commonly The selective plugging agents are Paraffin, polymer, gel, resin, and cement. But these agents only plug near the wellbore and cannot plug selectively. Microbial Selective plugging is a selectively plugging method using microbe and its bio product as the plugging agent. Microbe as the plugging agent has an advantage, microbe easier to transport through the pore rock and generate extracellular polymer (slime) when provided with a suitable nutrient. Slime production in the high permeability zones will plug the pores in those areas and divert fluid flow to the unswept regions of the reservoir resulting in increased oil production. (F. M. Cusack et al., 1992).

Parameters of Waterflood Oil Recovery Efficiency

The main purpose of waterflood is increasing oil recovery from the reservoir. There are 3 parameters of the waterflood oil recovery based on this Equation (James T. S. & William M. C., 1997):

$$E_R = E_V \times E_D \quad \text{.....(Eq.1)}$$
$$E_V = E_I \times E_A \quad \text{.....(Eq.2)}$$
$$N_p = E_R \times N \quad \text{.....(Eq.3)}$$

Where:
E_R=Efficiency Recovery
E_D=Displacement Sweep Efficiency
E_V= Volumetric Sweep Efficiency

E_A=Areal Sweep Efficiency
E_I=Vertical (Invasion) Sweep Efficiency
N= Oil-in-Place
Np=Oil recovered by Waterflood

Areal Sweep Efficiency
Areal Sweep Efficiency is the fraction of the reservoir area that swept by the waterflood to reservoir surface area. The following is Equation of Areal Sweep Efficiency, and shown in Figure 1. Waterflood Efficiency Recovery Parameters.

$$E_A = \frac{Area\ Swept}{Reservoir\ Surface\ Area\ (Pattern)} \quad \text{..... (Eq.4)}$$

Areal Sweep Efficiency depends on: oil and water flow properties, the injection-production well pattern that is used to flood the reservoir, areal permeability variation and directional, pressure distribution between injection and production well

Vertical Sweep Efficiency
Vertical sweep refers to the fraction of a formation in the vertical plane which water will contact, or defined as the hydrocarbon pore space contacted by injected water divided by the hydrocarbon pore space behind the water front (the water front is defined by its most forward position), Shown in Figure 1. Efficiency Recovery.

$$E_I = \frac{Vertical\ Cross\ Section\ Covered\ by\ Water\ Injection}{Vertical\ Cross\ Section\ Behind\ the\ water\ Front} \quad \text{.....(Eq.5)}$$

This will depend primarily upon the degree of vertical stratification existing in the reservoir Rock Permeability Variation. The vertical sweep efficiency is significantly affected by stratification due to the preferential movement of fluids in the more permeable zones.

Displacement Sweep Efficiency
Displacement sweep efficiency is the oil recovery due to waterflooding expressed as a fraction of the oil volume which existed at the beginning of the flood in that part of the reservoir which has been contacted by injected water, Figure 1. Efficiency Recovery.

$$E_A = \frac{Oil\ Production\ due\ to\ Waterflooding}{OOIP\ in\ Region\ Swept\ by\ Waterflood} \quad \text{.....(Eq.6)}$$

There are 5 factor that is effected to the displacement sweep efficiency fluid properties, rock properties, flow rate, pressure gradient, and structural properties of the reservoir (direction of flow).

Reservoir Rock Permeability Variations Effect
The reservoir rock permeability variations can influence to the performance of the waterflooding. That's caused by the water injection tends to flow in the high rock permeability and the oil inside the rock with lower zone permeability will be left behind, so the waterflood sweep Efficiency will be decrease. Shown in Figure 2. Permeability Variations Effect to the Water Injection. There are 2 Type of reservoir rock permeability variations, vertical permeability variation and areal permeability variation (James T. S. & William M. C., 1997).

Vertical Permeability Variation
Reservoir consist more than one layer in the vertical section, and every layer has a different rock properties, mentioned as rock stratification. This stratification can result from many factors including change in depositional environment, change in depositional source, and particle segregation.

Vertical rock reservoir permeability variation has influence to the waterflood performance than the other physical reservoir characteristic. It makes water injection tends to flood the high permeability zone, and the less permeability zone will be unflooded. Although, the waterflood will generally continue beyond breakthrough, and the oil rate production will reach the economic limit soon thereafter.

Areal Permeability Variation
Areal section of the reservoir rock have much less characteristic heterogeneity than the vertical section of reservoir rock. That's caused by a reservoir rock formation exhibit lateral continuity and the material deposited during a given geologic period should be of the same physical nature over a relatively large surface area. The changes in the environment or process of deposition, compaction, tectonic processes (which can cause fractures), or cementation, can cause large areal variations in the permeability of a reservoir.

Microbial Selective Plugging
The rock permeability variation cause the water breakthrough, and oil inside the less permeability zone will be unrecovered. To recover this unrecoverable oil, the flow of brine needs to be diverted from the already flooded areas (high permeability zones) to the unflooded areas (low permeability zones) by blocking the already established path of brine and forcing it to enter the lower permeability zones. This could be done by selective plugging of the highly permeable zones (already flooded areas).

This process need a strain of bacteria that form bio-polymer, bio-film, and/or biomass. Almost all of the kind of bacteria can produce biofilm to adhere in the pore rock surface. The bacteria that adhere in the pore rock will pile up and plug the pore. And the biomass can also produce while the bacteria grow and proliferate, so amount of the bacteria cell will increase. The increasing of the bacteria cell will amass in the surface of the pore rock and become restriction for the fluid which flow inside it.

There are some bacteria that can produce biopolymer in a form of slime. The function of biopolymer is for increase the thickness of the biofilm. The bacteria which can produce bio-polymer are *Bacillus Polymyxa, Brevibacterium Viscogenes, Leuconsostoc Mesenteroides, Xanthhomonas Campestris, Enterobacter Sp.*

Bacteria need an optimum environment condition for its growth and proliferate. So we need the reservoir data to make sure that the microbial selective plugging can be implemented in there. There is screening criteria for optimum environment growth condition bacteria in reservoir shown in Table 3. A General MEOR Screening.
There are 2 type of microbial selective plugging:

A. Plugging by Bacteria Dead Cells

The selective plugging can be achieved by increasing microbial dead cell mass caused by the microbial growth in the reservoir pore rock. The injected nutrient and microbes preferentially flow into the high permeability zones of the reservoir and as a result of cell growth, the biomass selectively plugs these zones to a greater extent than the moderate or low permeability zones (Crawford, 1961 & 1962). The example of microbe which can be implemented are Biomass Bacillus, Leuconostoc, Xanthomonas.
Based on the size ratio between microbes and pore throat, there are three type of bacteria dead cells plugging (Gruesbeck and Collins, 1979), shown in Figure 3. Three Types of Bacteria Cell Plugging Based on the microbes and Pore Throat Size Ratio. The first, the pore throat to microbe size ratio is more than 13 (d1/d2>13), there isn't significant plugging to the pore throat rock. Some microbes cell adheres to the pore rock surface but there are many bacteria cell flow through pore throat. The second, pore throat to microbe size ratio is equal to 4 until 6 (d1/d2= 4-6). There is a plugging in the pore throat caused by the microbe cell adhere to the pore throat surface and become the restriction to the other microbe cell which flow through it and pile up inside the pore throat. The third, pore throat to microbes size ratio is less than 26 (d1/d2 < 26). There is a filter cake plugging on the surface of the rock.

B. Plugging by Viable Bacteria Bioproduct

The microbes bioproduct from its metabolic process can also plug the pore rock, such as bio-polymer, and slime. The example of microbe which can be implemented are Bacillus, Brevibacterium, Leuconostoc, Xanthomonas. In water-flooding operations, in which water is pumped into injection wells in the reservoir in order to force the oil up to the surface, biopolymers plug high-permeability zones to redirect the water-flood to oil-rich zones in the reservoir and the sweep efficiency increases by equalizing the permeability across the reservoir (Casellas et al., 1997; Yakinov et al., 1995; Abu-Ruwaida et al., 1991).
Increasing biofilm inside the pore rock by live bacteria, make the bacteria colonize in the pore rock surface. The forming of an extansive biofilm can close the pore throat and effectively reducing the rock permeability, shown in Figure 4. Schematic Scheme of The Colonization in Solid Surface by Adherent Bacteria.

In 1987, J. Shaw has researched about the two types of the microbial selective plugging. He was comparing which one is more effective in reducing permeability. He used the Pseudomonas sp. isolated from the rock surface of Marmot Greek, Kananaskis, Alberta, and used two core plugging on dead and live cell bacteria. Cell suspension were 2-3 x 107 cell/ml and elapsed times were 23 and 29 hours for live and dead cells in. The result is live bacteria more effective in reducing rock permeability, shown in Figure 5. Decreasing Permeability caused by injecting live and dead cell suspensions (J. Shaw, 1982). The scanning electron microscope inspection show that the live bacteria had sealed the core with the cells and its slime, and the dead bacteria partially plugged the core surface with the clumps of the cell, Shown in Figure 6. Low-magnification Scanning Electron Microscope Image Showing (Size bar, 5 μm): a) Live bacteria produce polysaccharide (slime), and b) The clumps of dead cells of pseudomonas particularly plugging the glass bead model (J. Shaw, 1982).

Laboratory Test by Suthar et al.

In 2009, Microbial Selective Plugging had been observed by Suthar and his team from Microbiology and Biotechnology Department Centre, India. In their experiment, they used the Bacillus licheniformis TT33 was using because the bacteria is facultative anaerobic, halotolerant, thermotolerant, and bio-film forming microorganism. *Bacillus licheniformis* TT33 can produce Exopolymeric Substances and bio-surfactant. The *Bacillus licheniformis* TT33 was isolated from Tuva-Timba hot spring, Gujarat, India. There are two analysis in his experiment, the first is biofilm analysis of the *Bacillus licheniformis* TT33 and sand pack column experiment to know additional oil recovered (AOR) by the *Bacillus licheniformis* TT33

Biofilm Analysis

The first analysis in their research is biofilm from *Bacillus licheniformis* TT33 analysis. A standard microscopic slide (75×25 mm) was dipped in a 250 ml Erlenmeyer flask containing 50 ml of K. Jenny's medium, Table 1. Contains of K. Jenny's medium. This flask was then sterilized and inoculated with the strain under study. After 72 h of incubation at 37oC under static condition, the slide was removed from the flask and washed with distilled water. The images of the biofilm formed on the slide were collected by a LSM 510 META confocal microscope (Carl Zeiss, Germany).

The maximum Biofilm thickness, average biofilm thickness and the biomass volume can be measured by using COMSTAT (a software image analysis). And the result was the maximum biofilm thickness is 46.72±0.19 μm and average biofilm thickness is 33.23±7.73 μm indicated the formation of a dense biofilm on the substratum. The

biomass volume is 11.10±5.61 µm3/µm2 represented a high volume of biofilm cells present in a given confocal image stack [13]. Hence, COMSTAT analysis of the biofilm structure confirmed that a dense, and confluent biofilm was formed by *Bacillus licheniformis* TT33, shown in Figure 7. Biofilm image of Bacillus licheniformis TT33 obtained by confocal microscopy through live/dead Baclight staining (Suthar et. al., 2009).

Sand Pack Column Experiment

The sand pack column was designed to simulate an oil reservoir and used to check the selective plugging mechanism based oil recovery efficiency of *Bacillus licheniformis* TT33. The first of all, sand pack column was saturated by brine, than the brine was replaced by oil. And the sand pack was flooded with brine until there wasn't oil coming with the brine flooding.

After that, 0,6 pore volume of *Bacillus licheniformis* TT33 was injected witj the K. Jenny's medium to the sand pack, and incubated for 20 days at 50^{0}C. After incubation, the column was flooded with brine (10% NaCl) and the additional oil recovered (AOR) over residual oil saturation was measured. The following is the formula to calvulate the oil recovered by the Bacillus licheniformis TT33:

Pore Volume (PV) (ml) =Volume of brine required to saturate the column

Original Oil in Place (OOIP) (ml) =Volume of brine displaced by oil saturation

S_{orwf} (ml) = Residual oil saturation after water flooding

S_{orbp} (ml) = Oil collected over residual oil saturation after plugging

$$Initial\ water\ saturation\ (S_{wi}) = \frac{X}{PV} \times 100\% \quad \ldots(Eq.8)$$

Where,

X = Pore Volume – Volume of Brine replaced by oil .....(Eq. 9)

$$Initial\ oil\ saturation\ (S_{oi}) = \frac{OOIP}{PV} \times 100\% \quad ..(Eq.10)$$

$$Residual\ oil\ saturation\ (S_{or}) = \frac{X_i}{OOIP} \times 100\% \quad ..(Eq.11)$$

Where,

X_i = OOIP – Volume of oil recovered initial waterflood .....(Eq.12)

$$AOR = \frac{Oil\ recovered\ using\ plugging}{Oil\ in\ column\ after\ waterflood} \times 100\% \quad .(Eq.\ 13)$$

The sand pack column used in this experiment was carried out in triplicates, pore volume of the sand pack column was in range 54-65 ml. PV of the sand pack column was in the range of 54-65 ml. The volume of oil required to saturate the column was in the range of 45- 51 ml, which formed about 81.1±2.9% of the PV. Thereafter, brine flooding was able to recover about 53.1±2.6% of OOIP, leaving about 46.9±2.7% of oil unrecovered in the column, shown in Table 2. Oil recovery obtained in sand pack columns using *Bacillus licheniformis* TT33. At the end of the experiment, the packed sand was analyzed using environmental scanning electron microscopy (ESEM), shown in Figure 8. ESEM analysis of sand packed in column showing biofilm and bacterial cells (Suthar et. al., 2009).

Microbes in Reservoir Condition

Microbes has an optimum condition to growth and proliferate, so we have to make sure that reservoir condition compatible for it. Here I compare between optimum microbe growth condition (shown In Table 3. General MEOR Screening (Gammer-Eldeen Ahmed E. et al., 2013)) to the oilfields reservoir condition in six states of USA, collected by D. M. Munnecke and J.B. Clark, 1979. Every State consist of six data, are depth, temperature, pH, API Gravity, and porosity (Shown in Table 5, Table 6, Table 7, Table 8, and Table 9). There isn't reservoir pressure data from this data. So I was using oilfield reservoir pressure data from Indonesia oilfield, collected by Sri Kadarwati et al., 1999, then compare it to the general MEOR screening criteria (Shown in Table 4)

The optimum pressure for microbes to growth is under 600 atm, with limitation until 1160 atm. Compare to the Indonesia Oilfield data (Shown in Table 4) all of the oil field has an optimum pressure for microbes to grow and proliferate. But not only pressure which has to consider, so let's check the other parameter of general MEOR screening.

Reservoir depth can also give a negative effect to the microbes. The Depth limitation for microbe growth is less than 7800 ft. Based on the percentage of reservoir with depth data in six US states in Table 5, there are 5 states which has percentage of reservoir with Depth less than 7800 is more than 50. The highest percentage is 93,9% in Colorado with 853 reservoir numbers. And Compare to the Indonesia Oilfield data (Shown in Table 4) the potential reservoir depth for MEOR are Cepu, Rantau, and Prabumulih which have depth less than 7800 ft.

And then for the optimum temperature for microbes to growth is 30^{0}C – 50^{0}C, with limitation until 90^{0}C. Based on the percentage of reservoir with temperature data in six US states in Table 6, almost all of the reservoir temperature is under the limitation for microbes to grow, except for Mississippi. Mississippi has more than 58% reservoir with temperature more than 75^{0}C. It isn't a bad news, because the six US state still has good percentage of reservoir with optimum temperature for microbes to grow. It means that MEOR potentially can be implemented in there. And Compare to the Indonesia Oilfield data (Shown in Table 4) the potential reservoir for MEOR based on temperature, are Cepu and Rantau with reservoir temperature 53-65^{0}C for Cepu and 50-71^{0}C for Rantau.

The optimum pH for microbes to growth is 6-8, with limitation less than 9 and higher than 5. Based on the percentage of reservoir with pH data in six states of USA in Table 7, all States has percentage of reservoir with 6-7,9 pH number is more than 50% reservoir. The Highest percentage is Texas with 73 % reservoir with pH

compatible to the MEOR screening. It means that based on pH reservoir data percentage, MEOR can be implemented in there.

For The optimum API Gravity for microbes to growth is 30 - 40, with limitation higher than 15. Based on the oil field pH data in six states of USA in Table 8, almost all States has percentage of reservoir with API Gravity range 31 – 42 is more that 50% reservoir. The Highest percentage is Colorado with 78 % reservoir with API Gravity compatible to the MEOR screening.

And the last is Porosity, the porosity has to bigger enough for the microbe to migrate and live. The optimum porosity is more than 10%. Based on the oil field porosity data in six states of USA in Table 9, there are 5 oil field has percentage of reservoir with porosity 11 - >40 is more than 80%, but in New Mexico only 38.5% of it reservoir with porosity more than 10%. The Highest percentage is Mississippi with 95 % reservoir with porosity compatible to the MEOR screening.

Discussion

Microbial selective plugging can increase recovery efficiency of waterflood after breakthrough by plugging the high permeability zone and make water injection flow through the less permeability zone where the unsweep oil is (Unsweep zone). By through the unswept zone make the volumetric sweep efficiency (areal and invasion sweep efficiency) increase and the oil recovery efficiency of the waterflood after breakthrough will increase.

There are two types of microbial selective plugging, are bacteria dead cells plugging and viable bacteria bioproduct plugging. The bacteria dead cells plugging can be achieved by increasing microbial dead cell mass caused by the microbial growth in the reservoir pore rock. The microbes bioproduct from its metabolic process can also plug the pore rock, such as bio-polymer, and slime. In 1987, J. Shaw has researched about the 2 type of the microbial selective plugging. He was comparing which one is more effective in reducing permeability. He used the *Pseudomonas sp.* isolated from the rock surface of Marmot Greek, Kananaskis, Alberta, and used two core plugging on dead and live cell bacteria. And the result is live bacteria more effective in reducing rock permeability. That's because the dead bacteria cell was only particularly plug the pore rock and there are some dead cells can't resist the water injection flow. Different to the viable bacteria which can produce biofilm to adherent to the surface of pore rock, so it can resist the water injection flow. And it can produce the bioproduct, every nutrient that's injected, it will increase the bioproduct

Based on the Suthar and his team had observed about microbial selective plugging in two ways, the first is measure the biofilm thickness and then microbial plugging in sand pack column using *Bacillus licheniformis* TT33. The amount of unrecoverable oil (AOR=27.7±3.5%) recovered by Bacillus licheniformis TT33. it is proved that plugging using bacteria effectively to increase oil recovery But.It can't prove that its potential for MEOR in oil reservoir yet. We have to compare between the optimum of the microbe growth condition to the reservoir condition.

From that comparison between the General MEOR Screening criteria (Shown in Table 3) to the oil field reservoir condition data in Indonesia and percentage of reservoir with its characteristic in six States of USA (Shown in Table 4, Table 5, Table 6, Table 7, Table 8, and Table 9,). Based on reservoir data from four oil fields in Indonesia, there are Cepu and Cirebon which compatible to the optimum condition for microbes to grow based on general MEOR screening. Cirebon and Prabumulih has temperature more than 90^{0}C which more than Temperature limitation for MEOR. And from the percentage of reservoir with its characteristic data from six states of USA, all of the reservoir in six states has a good potential for MEOR. So it is possible to implement the microbial selective plugging in oil and gas reservoir.

Conclusion

1. Microbial selective plugging is one of MEOR method help increasing waterflooding recovery efficiency after water breakthrough/channeling by blocking the already established path of brine and forcing it to enter the low permeability zones, thus displacing oil from these areas. This could be done by selective plugging of the highly permeable zones (already flooded areas).
2. There are two type of of microbial selective plugging based on the condition of the microbe, are using dead cell bacteria, and using viable bacteria and its bioproduct. Based on the J. Shaw research, viable bacteria is more effective to selective plugging on pore rock than dead cell bacteria.
3. Based on the Suthar and his team research about microbial selective plugging in sand pack column using *Bacillus licheniformis* TT33. The amount of unrecoverable oil (AOR=27.7±3.5%) recovered by Bacillus licheniformis TT33, it is proved that plugging using bacteria effectively to increase oil recovery.
4. Based from the comparison between the General MEOR Screening criteria to the oil field reservoir condition data in Indonesia and percentage of reservoir with its characteristic in six States of USA, the result are:

a. Reservoir data from four oil fields in Indonesia, there are Cepu and Cirebon which compatible to the optimum condition for microbes to grow based on general MEOR screening criteria.

b. Based on the percentage of reservoir with its characteristic data from six states of USA, all of the reservoir in six states has a good potential for MEOR. It is possible to implement the microbial selective plugging in oil and gas reservoir.

Table 1. Contains of K. Jenny's medium (Suthar et al., 2009).

Contain	Concentrate
Glucose	10 g/l
NaNO3	2.8 g/l
KCl	0.5 g/l
MgSO4·7H2O	0.2 g/l
H3PO4	2 ml of 84%/l
CaCl2·2H2O	0.03 g/l
EDTA	0.2 g/l
ZnSO4·7H2O	0.8 mg/l
MnSO4 ·H2O	0.2 mg/l
H3BO3	60 µg/l
Na2MoO4·2H2O	20 µg/l

Table 2. Oil recovery obtained in sand pack columns using *Bacillus licheniformis* TT33 (Suthar et al., 2009).

Bacillus licheniformis TT33.	Column 1	Column 2	Column 2
PV (ml)	54	62	65
OOIP (ml)	45.5	50	51
X (ml)	8.5	12	14
S_{orwf} (ml)	25.5	25.9	26.2
S_{orbp} (ml)	8.1	6.5	7
S_{wi} (%)	15.74	19.35	21.53
Soi (%)	84.25	80.64	78.46
Sor (%)	43.95	48.2	48.62
AOR (%)	31.76	25.09	26.72

References

1. Donaldson E.C., Chilingarian G.V., Yen T.F. 1989, "Development in Petroleum Science: Microbial Enhanced Oil Recovery", Edinburgh: University of Heriot-Watt, pp. 7:125 -147
2. Ahmed Eltayeb Gammer-Eldeen, Al Mustafa Ali Adam Alhadi, Mohamed Abdelrahman Mergani. 2013, "Microbial Enhanced Oil Recovery", Sudan: University of Khortoum, pp. 2:38 -41
3. Suthar, Harish, Hingurao Krushi, Desai Anjana, Nerurkar Anuradha 2009, "Selective Plugging Strategy Based Microbial Enhanced Oil Recovery Using Bacillus licheniformis TT33".Jurnal of Microbiology and Biotechnology, Gujarat, India, pp. 3-7
4. Al-Sulaimani H., Joshi S., Al-Wahaibi Y., Al-Bahry S., Elshafie A., AlBemani A., 2016, "Microbial biotechnology for enhancing oil recovery: Current developments and future prospects". Oman:Sultan Qaboos University, p. 2:150.
5. Rashedi Hamid, Yazdian Fatemeh, Naghizadeh Simin, 2012, "Microbial Enhanced Oil Recovery". Irak: University of Tehran, pp. 3:72-78.
6. Raiders R. A., Maher T. F., Knapp R. M., McIlnerney M. J. 1966 "Selective Plugging and Oil Displacement in Crossflow Core Systems by Microorganisms". Unerversity of Oklahoma, Norman, Oklahoma. SPE 15600, pp. 1-4.
7. Smith T. James, Cobb M. William, 1997 "Waterflooding:Textbook" Dallas, Texas, 4:1-17, 5:2-6.
8. Garland M. Thomas, 1966, "Selective Plugging of Water Injection Wells" U. S. Bureau of Mines, Whichita Falls, Texas, pp. 1-3.
9. Cusack F.M., Singh S., J. Novosad, M. Chmilar, S. A. Blenkinsopp 1992,"The Use of Ultramicrobacteria for Selective Plugging in Oil Recovery by Waterflooding", University of Calgary, USA. SPE 22365, pp. 1-3.
10. Kadarwati Sri, Udiharto M., Hadi Noegroho, Indra Doria, 1999, "Selected Indonesian Microbes Potentials For MEOR". Society Petroleum Engineer Inc., SPE 57316, pp. 1-4.

Table 3. General MEOR Screening (Gammer-Eldeen Ahmed E. et al., 2013)

Factor	Limit	Optimum	Comment
Pressure	1160 atm	<600 atm	Extremely high pressure are troublesome to non adapted bacteria
Temperature	<90^{0}C	30^{0}C-50^{0}C	Depend on the microbe
API Gravity	>15	30-40	Heavier crude information wasn't sufficient
pH	>5, <9	6-8	Main Factor
Salinity	<10% NaCl <150000 ppm	-	-
Lithology	Not critical	carbonate	-
Depth	<7800 ft	-	Depend on the corresponding temperature
Porosity	>10 %	>10%	Not limiting
Permeability	>50 mD	>150mD	-
Oil Saturation	-	>25%	Successful trials with a low saturation was reported

Table 4. The Oil Field Reservoir Data in Indonesia (Sri Kadarwati et al., 1999)

Oil Field	Reservoir Rock Type	Depth (ft)	Pressure (atm)	Temperature (0C)
Cepu	Limestone, Sandstone	2227,7-3300,5	21-92	53-65
Cirebon	Limestone, Sandstone, Volcanic	3494-8320	85-182	100-139
Rantau	Sandstone	1010-2985,6	21-65	50-71
Prabumulih	Sandstone	3937-5433	32-125	86-112

Table 5. The Depth of Reservoir Data Percentage of Oil Field in Six States of USA (D. M. Munnecke and J.B. Clark, 1979)

U.S. State	Number of Reservoir	Percentage of Reservoir with depth (ft)						Percentage of Reservoir with Depth Potential for MEOR
		<2001	2001-4000	4001-5000	5001-7500	7501-10000	>10000	
Oklahoma	7286	14.3	30.5	12.9	26.3	11.4	4.6	84
Colorado	853	5	11.5	27.3	50.1	6	0.1	93.9
Texas	37606	5.7	19.1	13.6	34.1	20.1	7.3	72.5
Mississippi	1020	0.9	3.3	8.8	34.6	16.7	35.7	47.6
New Mexico	1079	10.7	17.1	10.3	16.6	19.8	25.5	54.7
Wyoming	1080	12.8	23.3	11.1	29.1	16.3	7.4	76.3

Table 6. The Reservoir Temperature Data Percentage of Oil Field in Six States of US (D. M. Munnecke and J.B. Clark, 1979)

U.S. State	Number of Reservoir	Percentage of Reservoir with Temperature (0C)					Percentage of Reservoir with Temperature Potential for MEOR
		<35	35-45	45-55	55-75	>75	
Oklahoma	24	0	36	44	16	4	80
Colorado	183	1	1.9	19	49.5	30	20.9
Texas	549	9.1	14.3	19	39.5	18.1	33.3
Mississippi	904	6	1	5	35	58	6
New Mexico	203	8	15	8.7	53	22.5	23.7
Wyoming	256	13	10	20	34	36	30

Table 7. The Reservoir API Gravity Data Percentage of Oil Field in Six States of USA (D. M. Munnecke and J.B. Clark, 1979)

Oil Field in U.S. State	Number of Reservoir	Percentage of Reservoir with API Gravity			
		01-17.	17-31	31-42	>42
Oklahoma	8071	0.3	6.7	72.1	21
Colorado	525	0.4	8.6	78.3	12.5
Texas	37997	1.6	9.8	47	41.6
Mississippi	979	2	12.7	54.6	30.6
New Mexico	835	0.1	9.9	54	35.9
Wyoming	751	4.1	31.2	51.1	13.6

Table 8. The Reservoir Porosity Data Percentage of Oil Field in Six States of USA (D. M. Munnecke and J.B. Clark, 1979)

U.S. State	Number of reservoir	Percentage of Reservoir with porosity (%)				Percentage of Reservoir with Temperature Potential for MEOR
		0.1-10.9	11.0-17.9	18-25.9	>40	
Oklahoma	346	8.1	56.6	32.5	2.8	91.9
Colorado	410	11.9	44.4	41.5	1.7	87.6
Texas	4445	19.5	38.7	28.6	15.7	83
Mississippi	1011	3.8	23.3	24.2	48.2	95.7
New Mexico	475	61.3	26.9	11.6	0	38.5
Wyoming	531	17.7	56.5	23.9	1.9	82.3

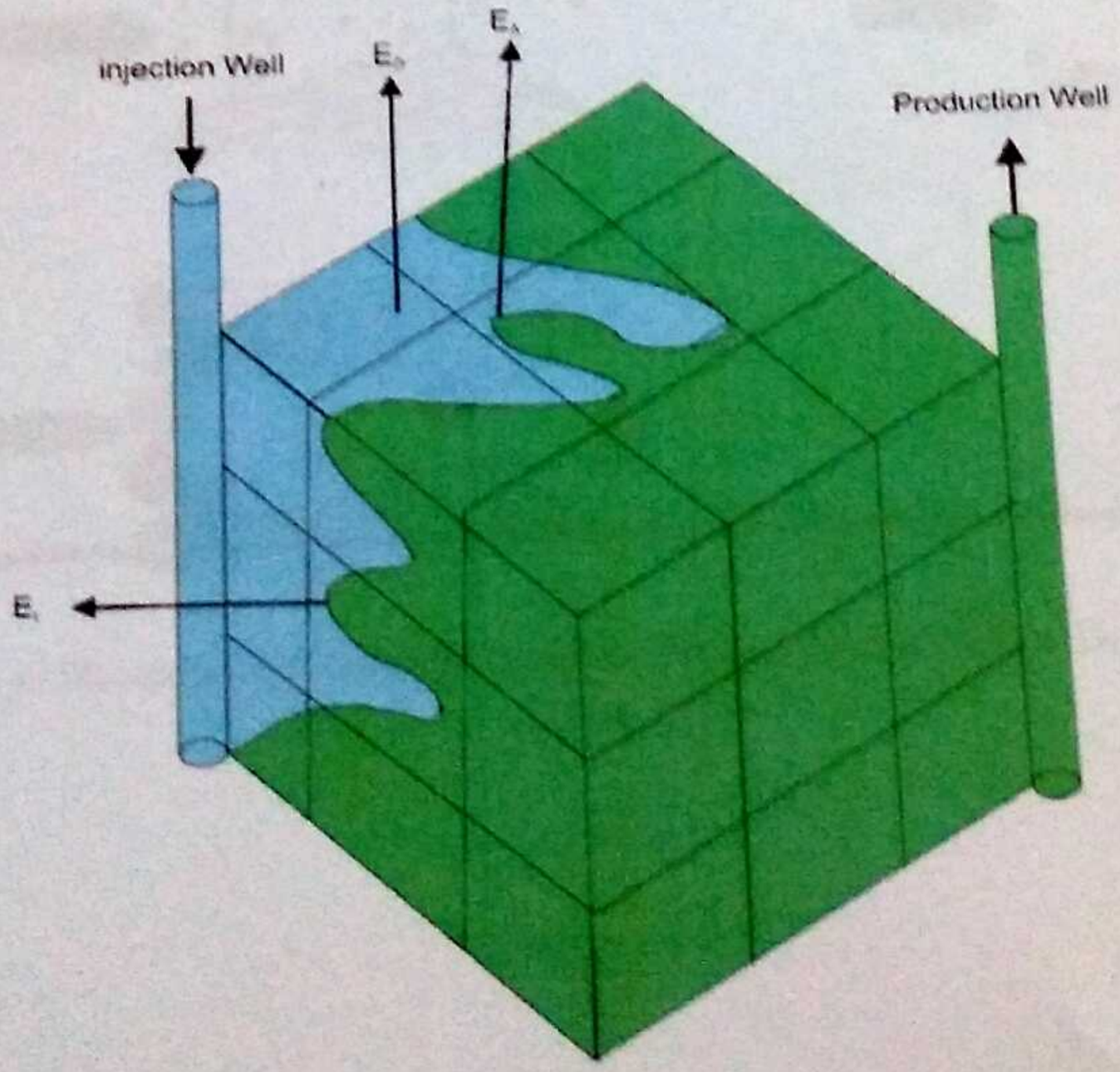


Figure 1. Waterflood Efficiency Recovery Parameters.

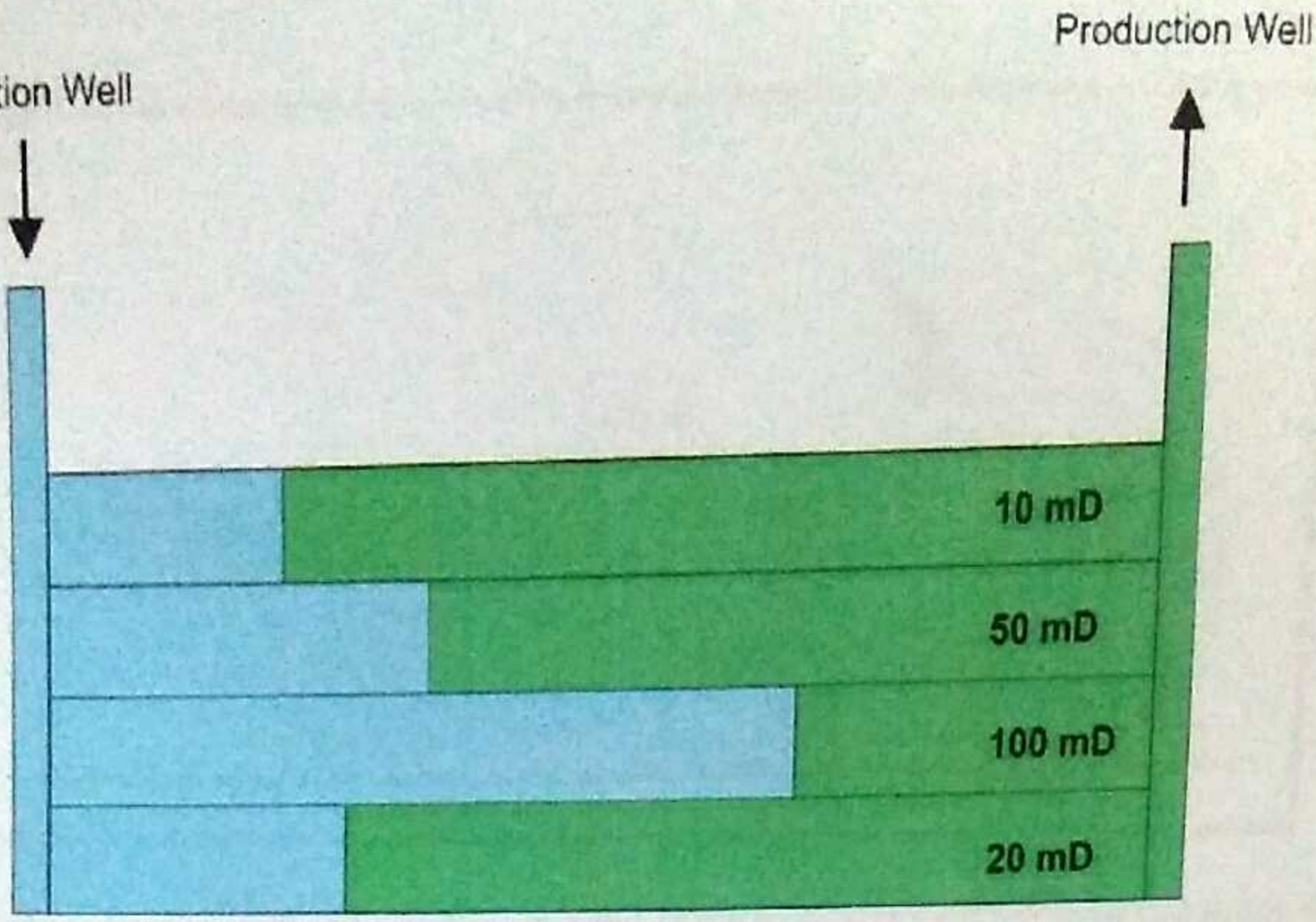


Figure 2. Permeability Variations Effect to the Water Injection.

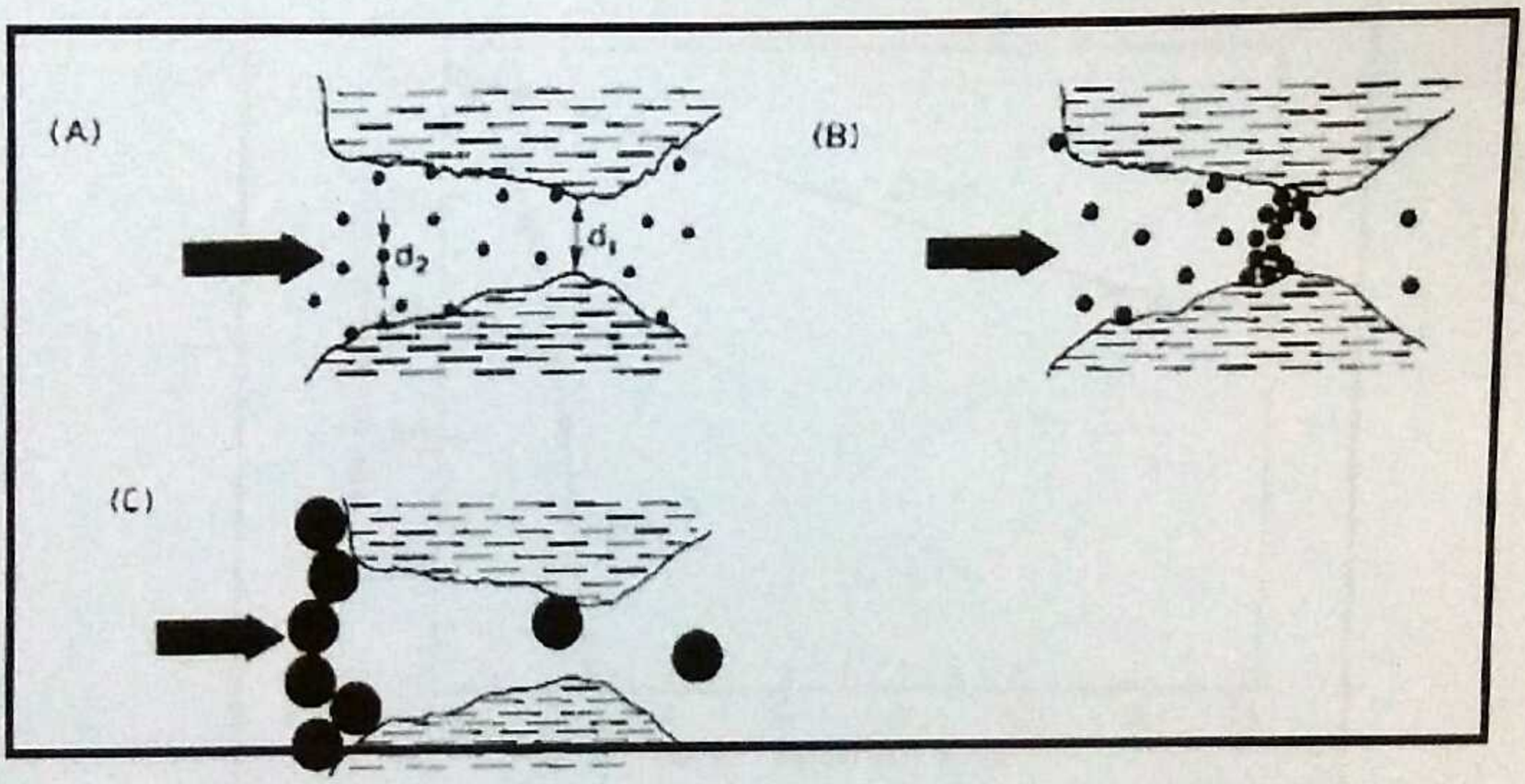


Figure 3. Three Types of Bacteria Cell Plugging Based on the microbes and Pore Throat Size Ratio (Gruesbeck and Collin, 1979).

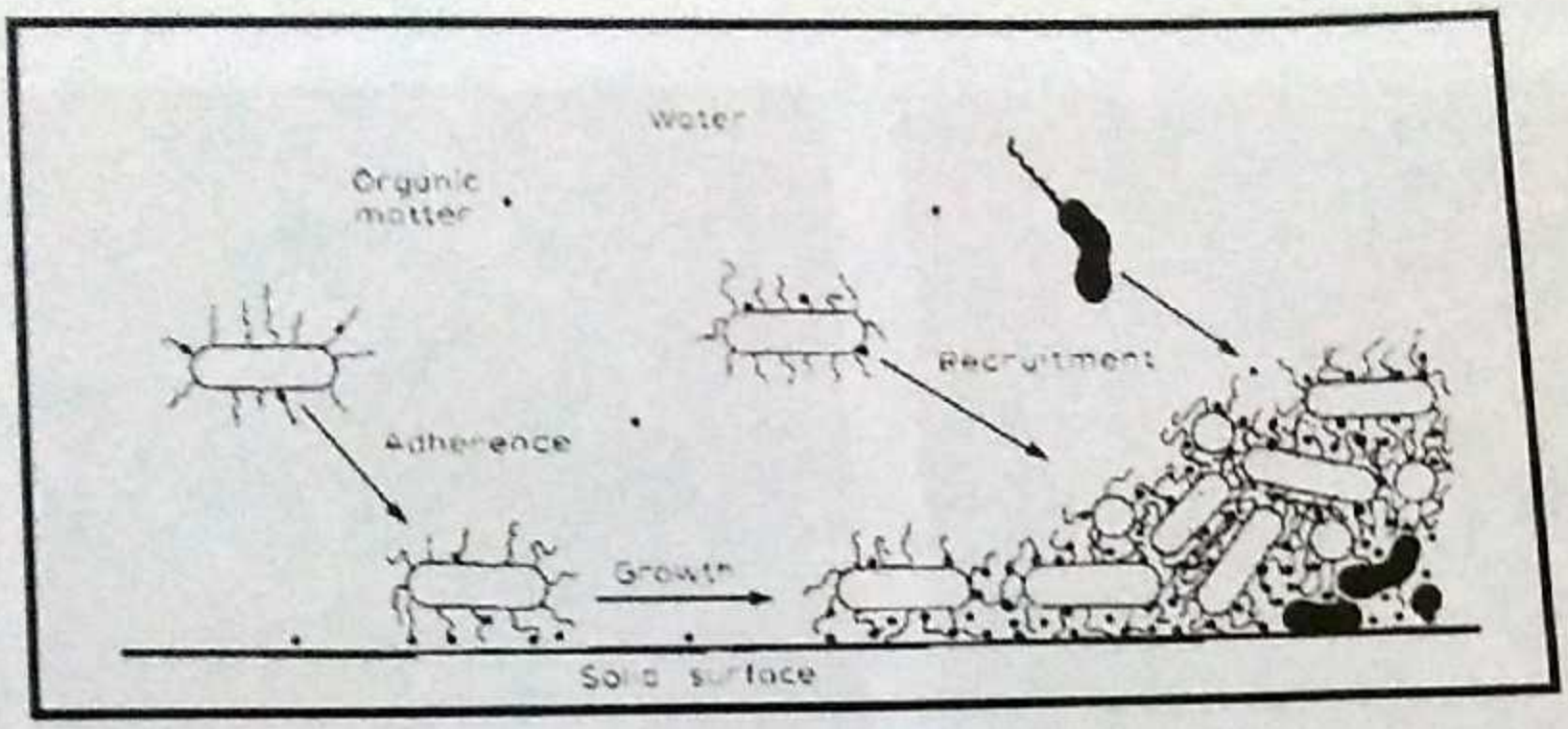


Figure 4. Schematic Scheme of The Colonization in Solid Surface by Adherent Bacteria (Tosteson et al., 1982).

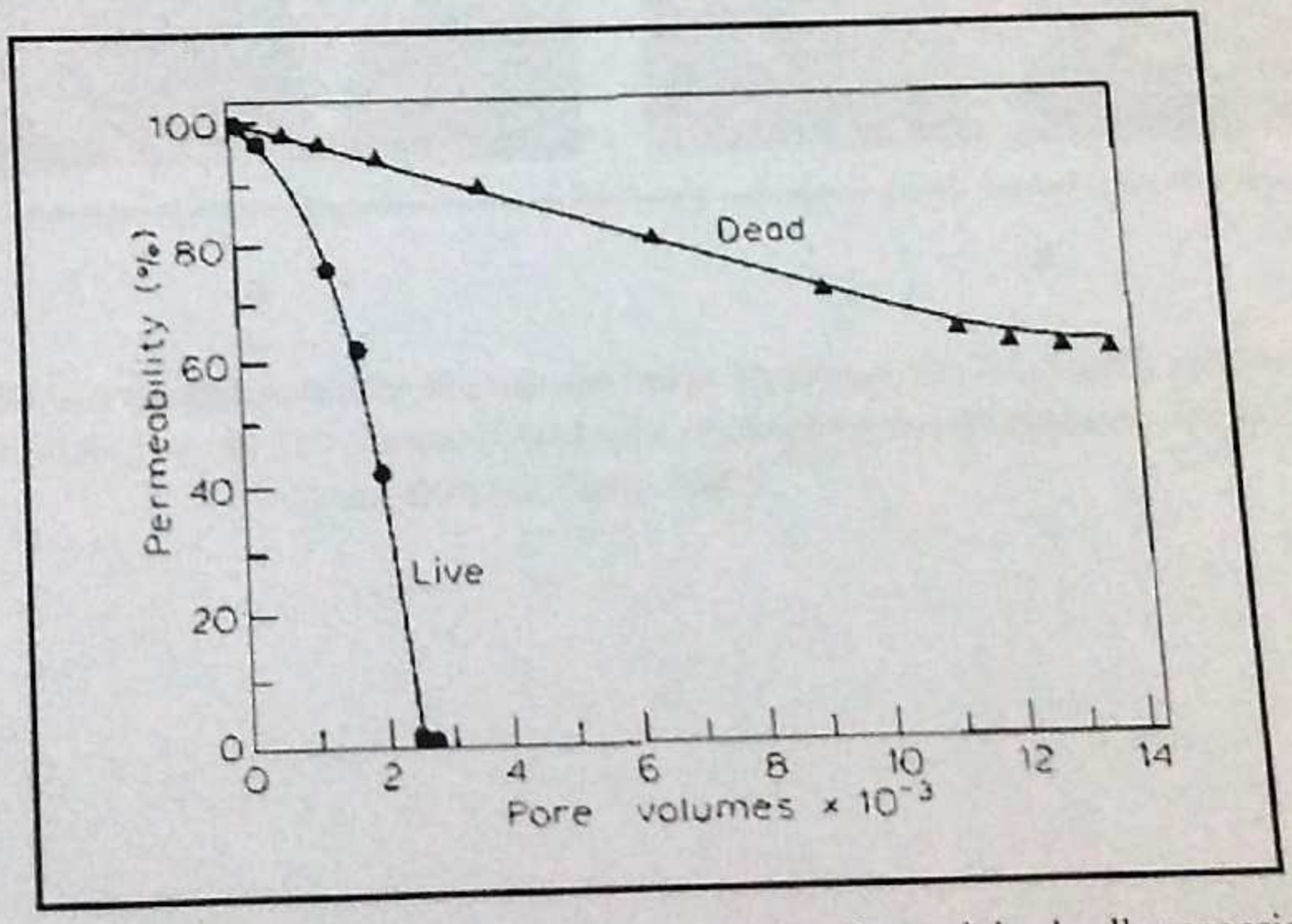
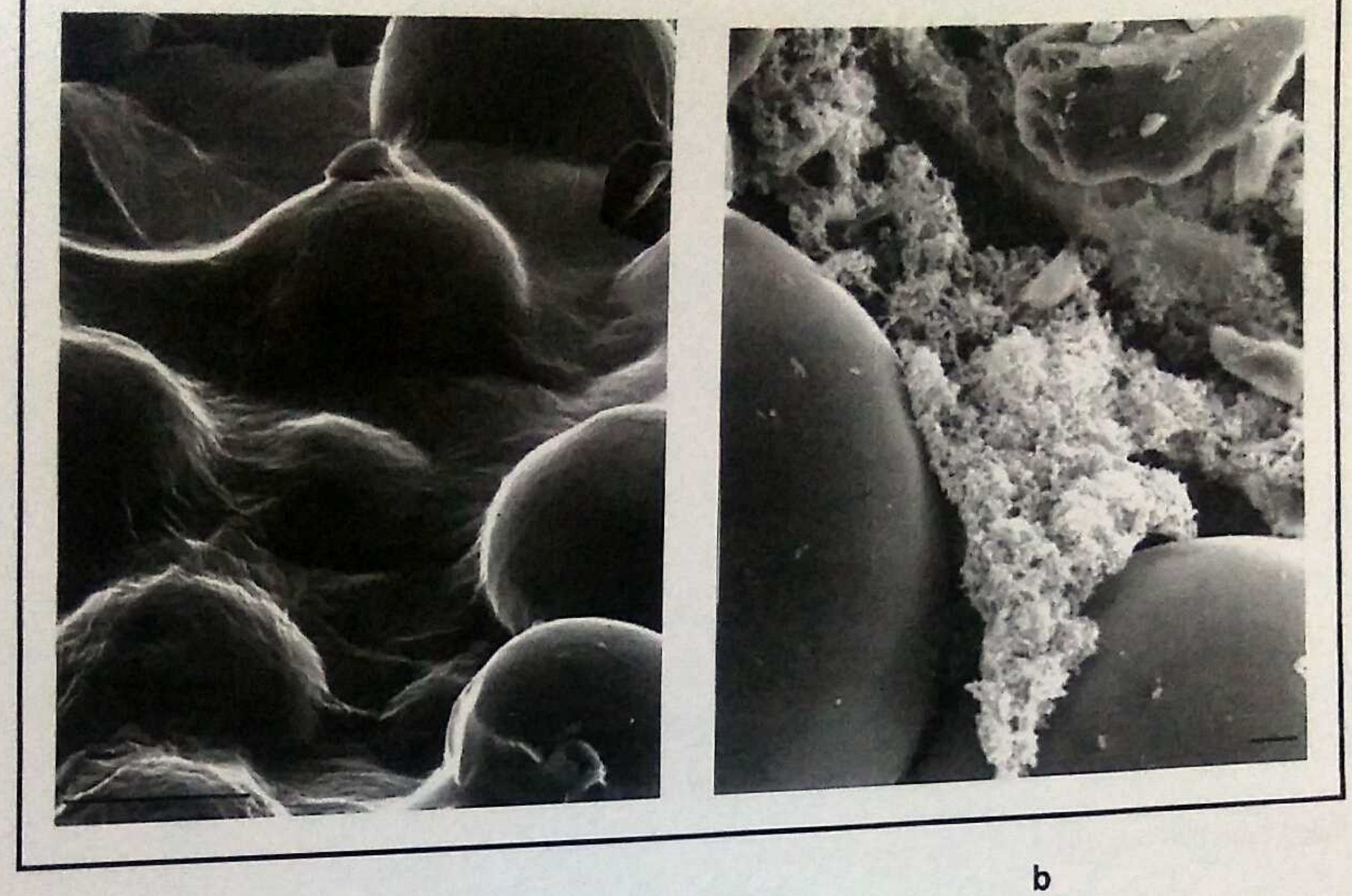


Figure 5. Decreasing Permeability caused by injecting live and dead cell suspensions (J.Shaw, 1982).



a b

Figure 6. Low-magnification Scanning electron Microscope Image Showing (Size bar, 5 μm): a) Live bacteria produce polysaccharide (slime), and b) The clumps of dead cells of pseudomonas particularly plugging the glass bead model (J. Shaw, 1982).

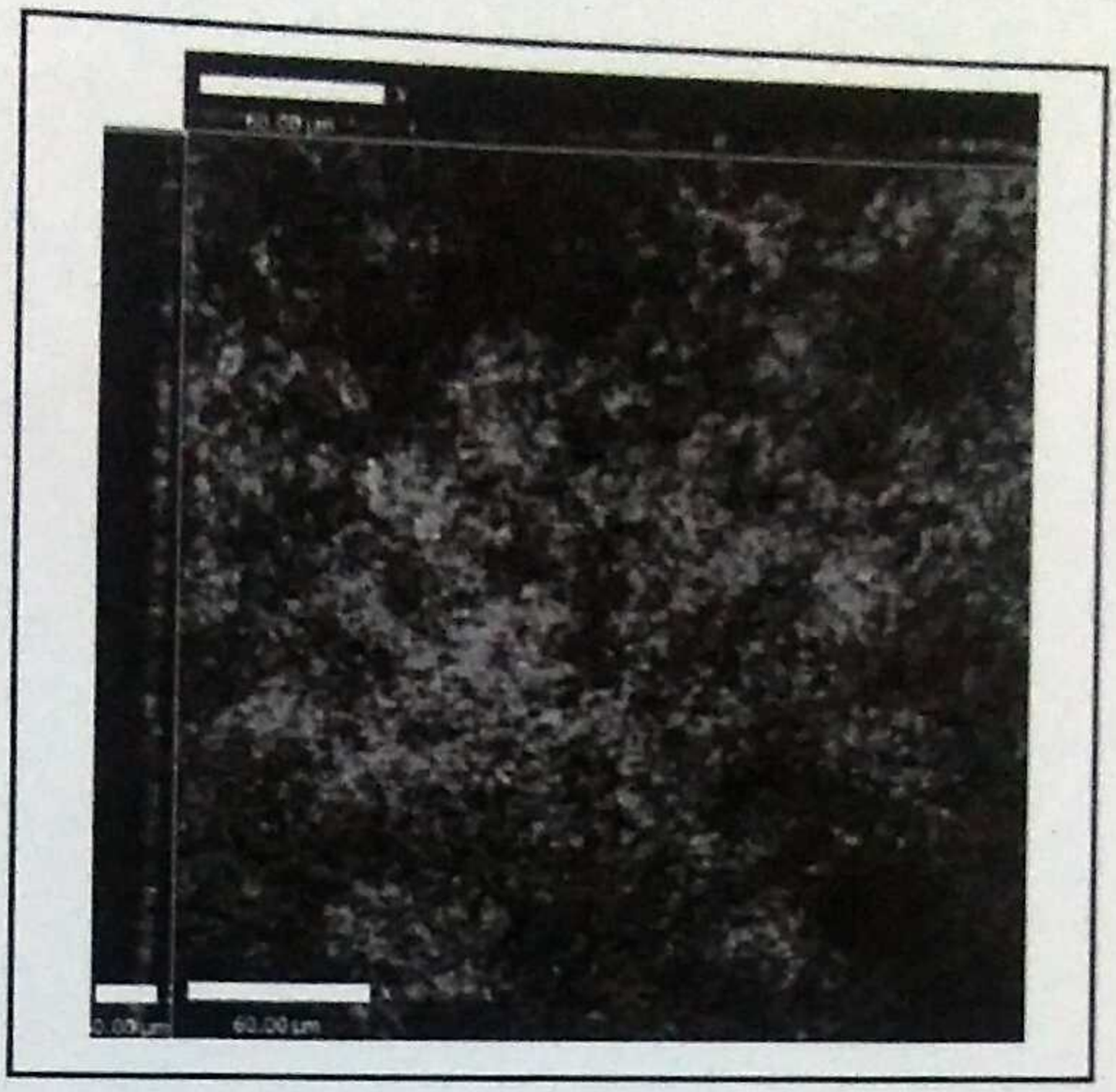


Figure 7. Biofilm image of Bacillus licheniformis TT33 obtained by confocal microscopy through live/dead Baclight staining. (Suthar et al., 2009).

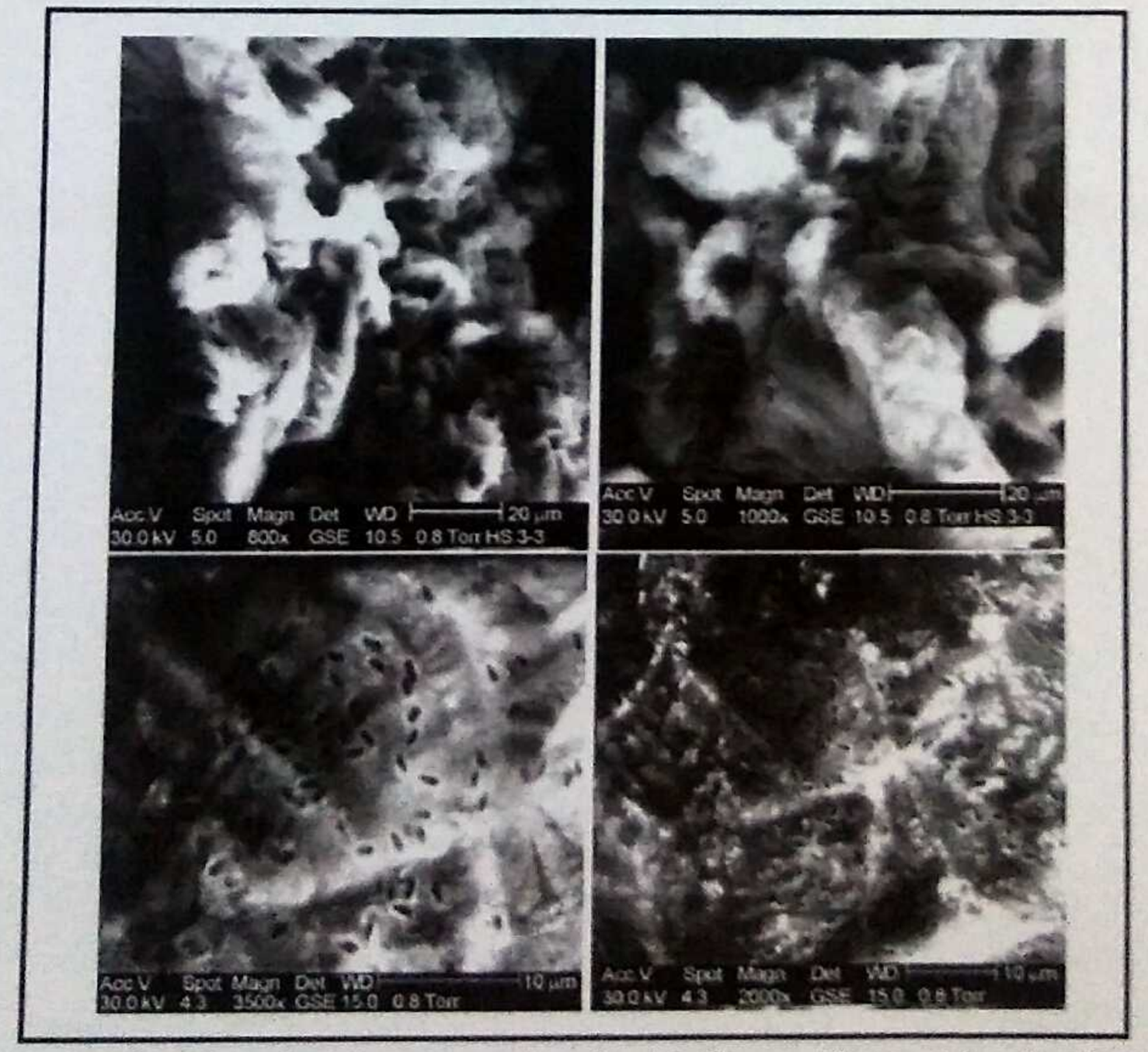


Figure 8. ESEM analysis of sand packed in column showing biofilm and bacterial cells (Suthar et al., 2009).