

Optimal Conditions for Bacillus Licheniformis Bacteria in Microbial Enhanced Oil Recovery

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ABSTRACT

According to today's too old oil wells available in the world, MEOR method can be very effective for increasing of oil tanks exploitation. In general, purpose of this paper is to obtain a set of optimal conditions of using microbes by creation of which the efficiency level of tanks exploitation will be raised. We used Bacillus Licheniformis bacteria in our experiments and our goal is to create suitable conditions for this kind of bacteria in terms of temperature, PH and salinity that can be used for increasing efficiency level of oil tanks exploitation. In our experiments, obtained efficiencies in salinity values of 0 ppm to 100000 ppm and in temperatures of 40 °C to 70 °C were compared to show that highest efficiency in these ranges will be obtained at 40 °C and 50000 ppm NaCl. In addition, we obtained IFT values at different temperatures (30 °C, 40 °C and 50 °C) and PH values (6 to 8) and also the effect of these bacteria on permeability and porosity changes at different salinities. We can conclude that in certain conditions, using this type of bacteria will reduce porosity and permeability. Finally, according to obtained results of these experiments, optimal conditions for creation of a favorable environment for the bacteria of Bacillus Licheniformis are determined or in other words we want to determine circumstances in which we have highest efficiency and lowest amount of IFT.

KEYWORDS: optimal conditions, Bacillus Licheniformis, MEOR potential, porosity and absolute permeability, interfacial tension (IFT)

INTRODUCTION

Lack of fossil energy resources and their increasing consumption rate in today's world has doubled importance of oil resources. Considering low percent of oil tanks exploitation, investigation of methods for enhanced rate of oil exploitation have been considered. Generally, oil exploitation is divided into three categories:

First, after drilling of wells and reaching reservoirs, naturally available oil flows toward the outlet openings of the wells based on pressure difference inside the tank by help of which it will be possible to extract 30 to 50 percent of total oil in the reservoir this method is called natural method (first step).

Second step of oil exploitation includes following steps:

A) Chemical methods such as polymer flooding, surfactants flow, alkaline flow.

B) Thermal methods such as steam flow, hot water, combustion.

C) Gas injection methods including CO₂ injection, N₂ and combustion gases injection.

After extraction by the help of methods in second step, about 30 to 50 percent of oil can be remained in non-extracted form. Here, oil extraction will be performed using following methods.

1 - Using Micellar solution followed by using polymer solutions injected to wells as a buffer (this solution contains water, surfactants, salt and oil.)

2 - Using nuclear explosion methods that cause creation of artificial gaps in reservoir rock.

3 - Using microorganisms in oil industry called as enhanced oil exploitation with microbial method (MEOR) that dates back to 1926 (Beckman) and 1940 (Zobell). They suggested process of oil recycling using anaerobic microbes and dissolution of sulfate minerals. [1]

Bacillus Licheniformis is one of the bacteria that it is used in enhanced oil exploitation from reservoirs and today it has many applications.

In general, there are common methods for using Bacillus Licheniformis to increase efficiency of oil exploitation from reservoirs. These methods are as follows:

1) Ex.situ method: In this method, microbial products such as surfactants are added to the tank after separation and purification.

2) In.situ method:

A) Stimulation of microbial population in the reservoir by injecting nutrients to increase microbial activity

B) Injection of such microbes associated with nutrients into the reservoir. These microbes can have appropriate activity in the reservoir and they can produce products that cause oil mobility.

Among proposed methods, in.situ is more appropriate. In addition, part b in in.situ method is considered better. Because in ex. situ method the input materials may quickly be degraded by microbes present in the tank due to biodegradable products. 2

- A. method is not also appropriate because type and mode of microbial activity is not clear.

For using 2-B method, first, effect of different conditions of reservoir on injected bacteria should be known. Next, bacteria for injection and type and amount of nutrients should be determined based on these conditions.

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Bacillus Licheniformis is a type of bacteria used in oil reservoirs. Aerobic *Bacillus* may play a role in production of surfactant, acid, gas and etc. Therefore, these bacteria can be used in enhanced oil exploitation from reservoirs. Moreover, these bacteria are useful for removing asphaltene sediments around wells and since they can produce gas and surfactant, we can use them to troubleshoot the oil trapping in reservoirs and since they can produce acid, we can use them in sandstone and carbonate reservoirs and in these reservoirs if suitable conditions be prepared, they can increase permeability value and then increase oil exploitation.[1] We should notice that in some cases and in certain conditions, using these bacteria will reduce permeability and also this process may improve the sweep efficiency. [2], [3], [4]

Bacillus Licheniformis can produce a variety of materials depending on the environment in which they grow. For example, it is possible to set PGA or exopolymer production by these bacteria via monitoring of sucrose value in their medium. [5], [6]

MATERIALS AND METHODS

Experimental procedure

In this experiment, bacteria are grown in two different growths medium. We grow *Bacillus Licheniformis* in a medium including 2% sucrose, 0.02% NH_4Cl , 0.01% $(\text{NH}_4)_2\text{HPO}_4$ to determine optimal point and to show the effect of various parameters such as temperature and salinity on efficiency, porosity and permeability.[7],[8] We also grow *Bacillus Licheniformis* in a medium containing 100mM phosphate buffer, 0.25 g / l MgSO_4 , 1g / l $(\text{NH}_4)_2\text{HPO}_4$, 1% glucose, 1% trace metal solution and 2g / l yeast extract to show the effect of temperature and PH on IFT .[9]

Nutrients used in these experiments included 2% sucrose and 0.01% $(\text{NH}_4)_2\text{HPO}_4$. [3]

This experiment is performed by considering a column of sand as porous media. Sand column is flooded by brine with desired salinity, temperature and PH value followed by flooding sand column by oil with pre-determined characteristics. We repeat this act until no brine comes out of sand column. In this case, amount of brine in the sand column is S_{wc} . Then, 0.2 PV of bacteria solution with 0.2 PV of nutrients solution will be injected into sand column in order to observe changes. After doing so, again sand column will be flooded by brine with previous characteristics and S_{or} value will be measured.

It should also be noted that to obtain recovery efficiency, we flood sand column by brine without injection of bacteria and nutrients and in this case S'_{or} will be obtained.

After obtaining S_{or} in each step, recovery efficiency can be calculated from following equation: [8]

$$\text{Recovery efficiency} = (S'_{or} - S_{or}) / S'_{or} \times 100 \quad (1)$$

We perform this experiment at different temperatures and salinities to calculate MEOR potential, porosity and permeability.

According to the importance of PH and temperature on IFT value [10], to illustrate the effect of PH and temperature on IFT, we can also perform this experiment at different temperatures and different amounts of PH value.

Pendant drop method can be used to measure IFT. In this method, the related cell can be pressurized using brine with desired PH and also we can adjust the system temperature. Finally, IFT can be measured.

At last, we calculate optimal conditions for this type of bacteria according to obtained results.

RESULTS

To illustrate the effect of salinity on MEOR potential, we perform this experiment at salinities of 0, 3, 5,7,10 percent of NaCl and at temperatures of 40°C and 70 °C. In this case we found the following results (PH = 7).

Table.1: The results of the effect of salinity on microbial recovery

Salinity (NaCl% w/v)	Temperature (°C)	MEOR Potential (%efficiency)
0	40	11.8
3	40	29.3
5	40	33.9
7	40	32.7
10	40	20.3
0	70	1
3	70	5.86
5	70	7
7	70	6.46
10	70	2.5

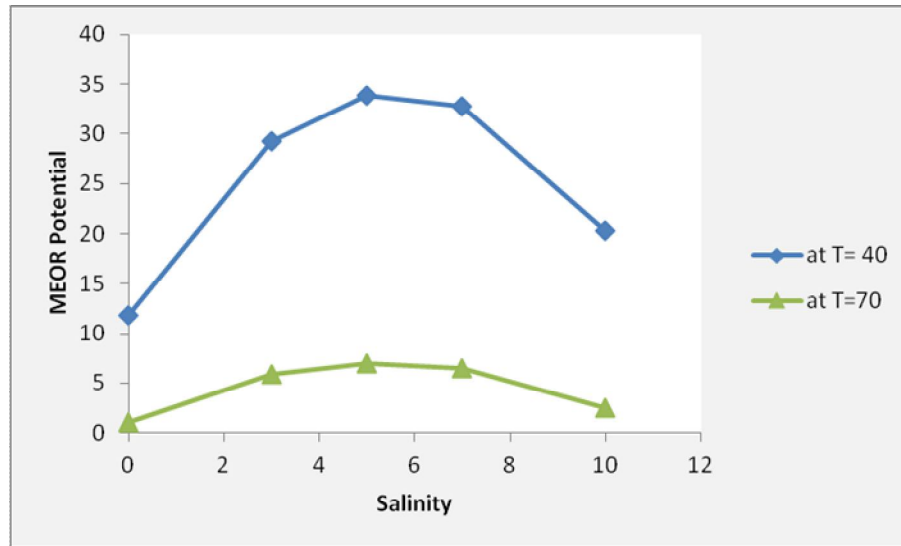


Fig.1: Effect of salinity on MEOR potential for Bacillus Licheniformis

To illustrate the effect of temperature on MEOR potential, experiments were performed at temperatures of 40 °C to 70 °C and salinities of 0% and 5% NaCl. In this case, following results were obtained (PH = 7).

Table.2: The results of the effect of temperature on microbial recovery

Temperature (°C)	Salinity (NaCl% w/v)	MEOR Potential (%efficiency)
40	0	12
50	0	10.67
60	0	7
70	0	1
40	5	34
50	5	26
60	5	15
70	5	7

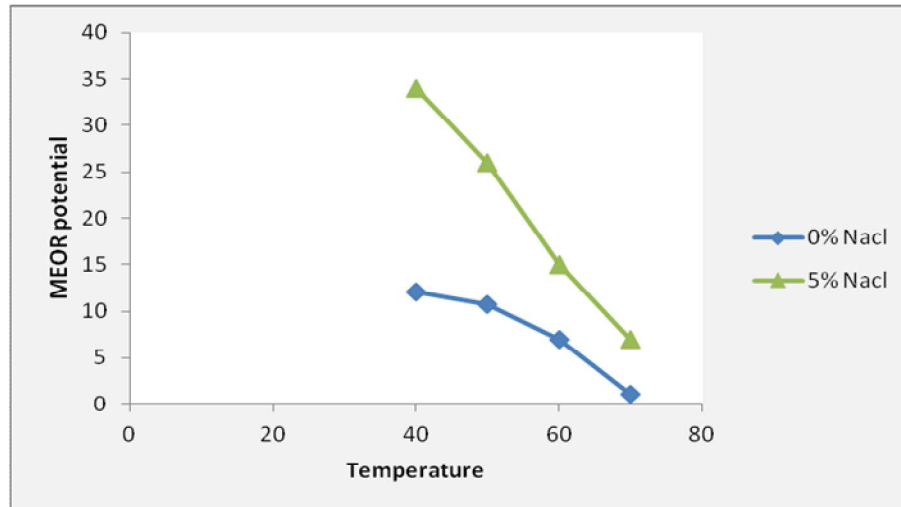


Fig.2: Effect of temperature on MEOR potential for Bacillus Licheniformis

In this part of experiment, we keep temperature constant at 40° C to observe the effect of salinity on porosity and absolute permeability. In this case, we obtain following results (PH = 7).

Table.3: The results of the effect of salinity on porosity

Salinity (NaCl% w/v)	Temperature (°C)	Porosity Ø (%)
0	40	34.1
3	40	33.39
5	40	33.3
7	40	33.5
10	40	34.4

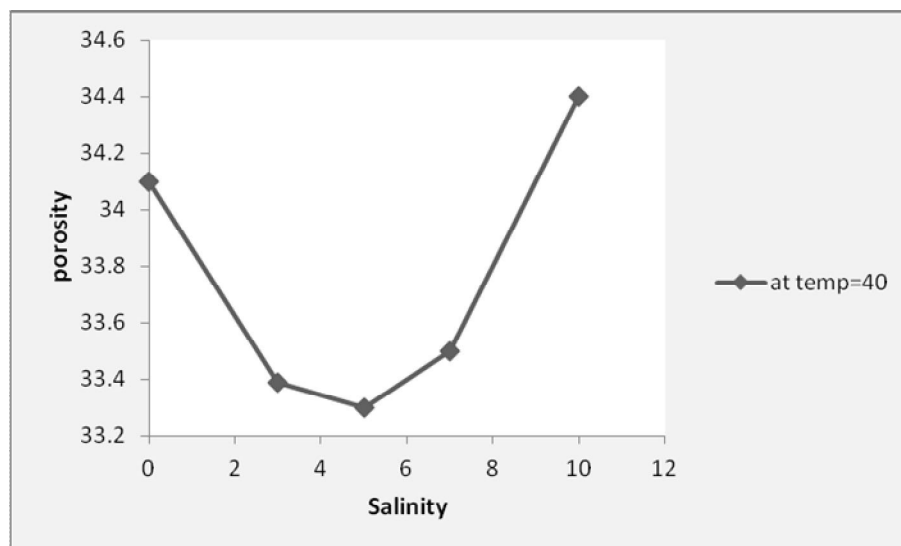


Fig.3: Effect of salinity on porosity for Bacillus Licheniformis at PH=7

Table.4: The results of the effect of salinity on K_{abs}

Salinity (NaCl% w/v)	Temperature ($^{\circ}$ C)	Absolute permeability K_{abs} (Darcy)
0	40	31.5
3	40	36.4
5	40	39
7	40	41
10	40	43.1

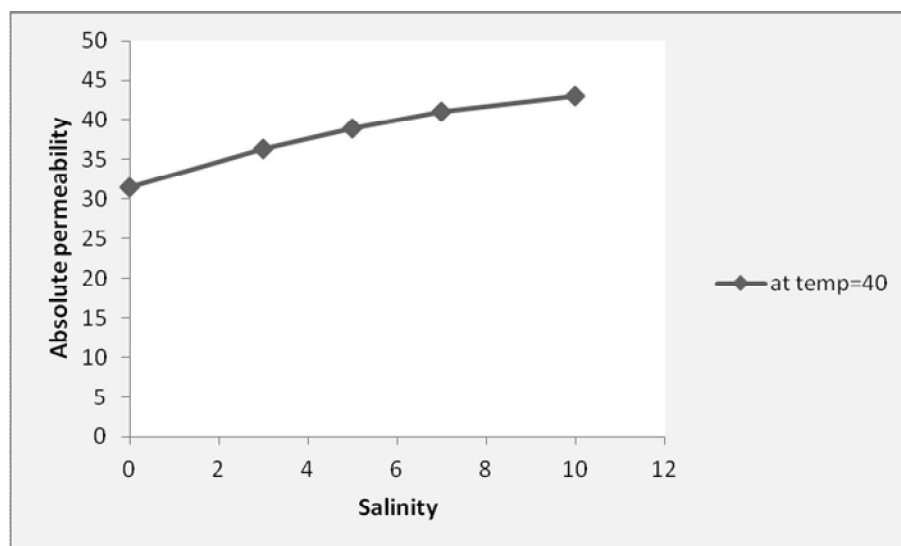


Fig.4: Effect of salinity on absolute permeability for Bacillus Licheniformis at PH=7

In another part of this experiment, our goal is to show the effect of PH and temperature on IFT. In order to see the effect of PH on IFT, we change its value from 6 to 8. For observing the effect of temperature change on IFT, we set PH value at 7 and change amount of temperature (IFT value can be calculated through pendant drop method). In this case, following results are obtained.

Table.5: The results of the effect of PH on IFT

PH	Interfacial tension (mN/m)
6	0.48
7	0.3
8	3.64

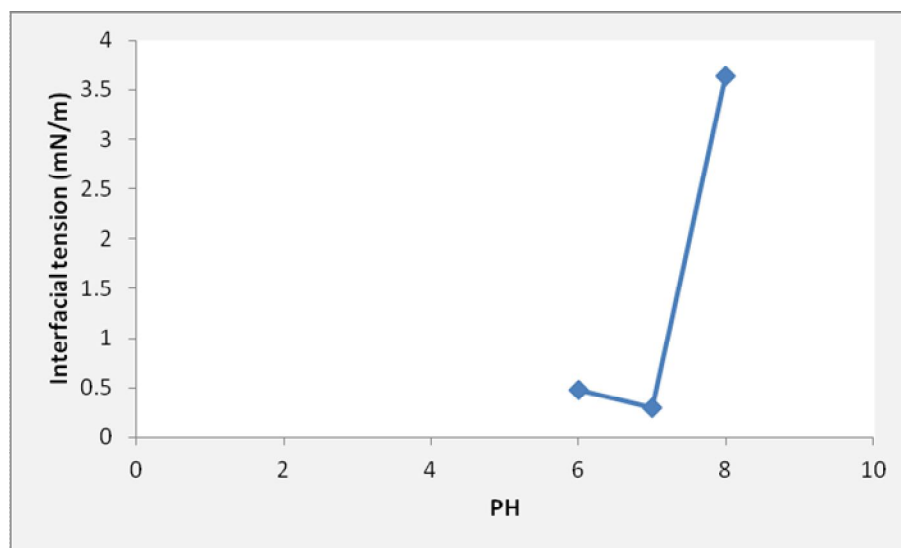


Fig.5: Effect of PH on interfacial tension for Bacillus Licheniformis

Table.6: The results of the effect of temperature on IFT

Temperature (°C)	Interfacial tension (mN/m)
30	0.42
40	0.35
50	0.28

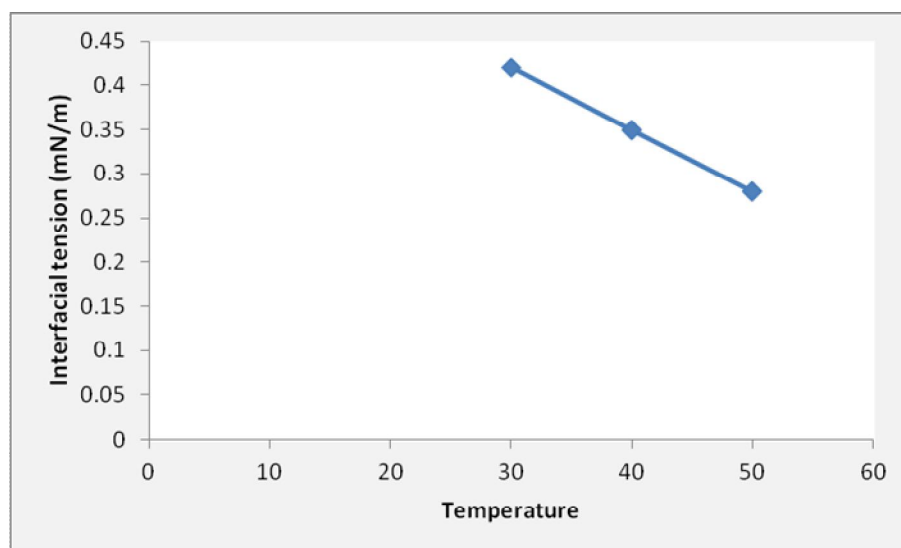


Fig.6: Effect of temperature on interfacial tension for Bacillus Licheniformis

Finally, according to obtained results, relationship between recovery efficiency and absolute permeability can be obtained. In this case, we notice that PH = 7 and temp = 40 °C and the results are obtained at same salinities (from 0% to 10%).

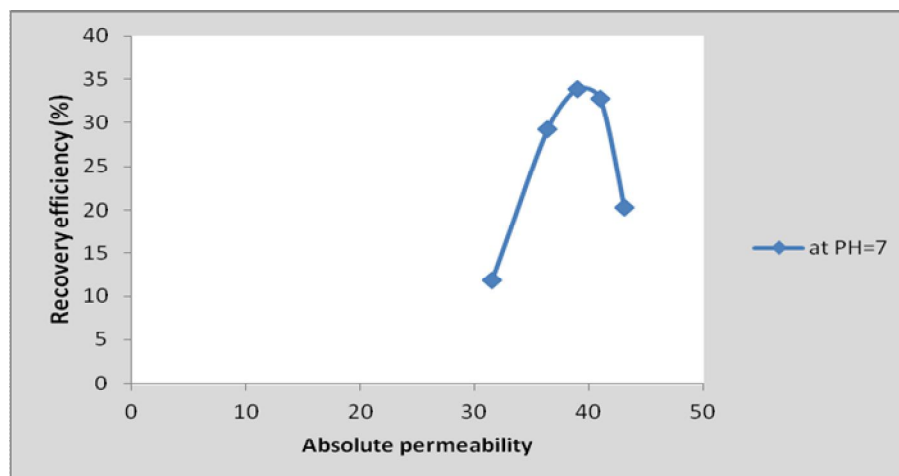


Fig.7: Relation between efficiency and absolute permeability

Conclusion

According to experiments and obtained results, following points can be raised:

- 1) About salinity effect on efficiency, it can be said that highest amount of MEOR potential can be obtained in salinity of 5% NaCl and at temperature of 40 °C.
- 2) About effect of salinity on porosity and absolute permeability, figures show that at temperature of 40 °C, lowest amount of porosity can be obtained in salinity of 5% NaCl and highest amount of absolute permeability can be obtained in salinity of 10% NaCl.
- 3) In the case of effect of temperature on the efficiency, we conclude that efficiency gradually decreases with increasing of temperature.
- 4) In the case of PH and temperature effect on IFT, it can also be said that highest amount of IFT in PH = 8 occurs due to decreased surfactant production in this PH value. On the other hand, IFT value is decreased with increased temperature.

Finally, according to obtained results of performed experiments, it can be said optimal conditions for *Bacillus Licheniformis* includes 5% NaCl, PH = 7 and temperature of 40 °C. Because in these conditions, highest level of efficiency and lowest IFT value may occur that are considered as two important parameters. Moreover, there are appropriate porosity and absolute permeability in these circumstances.

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