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Enhanced oil recovery by sand packed column supplemented with biosurfactants produced by local oil fields bacteria

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Abstract

In the present study, the free cell supernatant (decellularized) biosurfactants of two selected isolate *Bacillus cereus* ASWISA8 strain and *Enterobacter aerogenens* B19 strain were used for enhanced oil recovery by sand packed column, which was designed for enhanced oil recovery test by calculating the sand volume (SV), porosity, initial oil saturation(Soi), percentage rate of oil recovery (Swi), residual oil saturation (Sor), where the volume of oil recovered (Sor FW) was recorded and additional oil recovered (AOR) due to crude biosurfactant was calculated. The results showed that additional crude oil was recovered at about (32.39%) when treated with free cell supernatant biosurfactant produced by *Bacillus cereus* ASWISA8 and (25.33%) with free cell supernatant bioemulsifier produced by *Enterobacter aerogenes* B19.

Keywords: Biosurfactants, Bacteria, Sand packed column, Enhanced oil recovery.

Introduction

The microorganisms produce a variety of metabolic products that Potentially useful for enhanced oil recovery mechanisms (Sen, 2008). Generally, these products can be classified according to their functionality into seven major groups: biosurfactants, biopolymers, biogases, bioacids, biosolvents, biomass, and emulsifiers (She *et al.* 2019).

One of the most efficient mechanisms in MEOR processes are biosurfactants (Bordoloi and Konwar, 2008; Brown, 2010; Zhao *et al*., 2018; Alvarez *et al*., 2020). They are secondary metabolic amphipathic substances produced by a variety of microorganisms consisting of two parts, a polar head (hydrophilic) moiety may be ionic (cationic or anionic), non-ionic or amphoteric, and other parts nonpolar tail (hydrophobic) is often a chain of hydrocarbons (Silva *et al*., 2014; Mao *et al*., 2015; Saravanan *et al*.,2020). Surfactants can decrease the interfacial tension of the liquids by accumulating at the interface of immiscible fluids and increase the mobility and solubility of hydrophobic (water-hating) or insoluble organic compounds (Shivlata & Tulasi 2015; Zenati *et al*., 2018; Saravanan *et al*., 2020).

The application of biosurfactants in EOR is one of the most promising advanced techniques to recover a significant proportion of the residual oil in the reservoir. The remaining oil is commonly settled in regions of the reservoir that are troublesome to access, and the oil is trapped in the pores by capillary pressure (Sen, 2008; Speight, 2013). Biosurfactants reduce the interfacial tension between oil/water and oil/rock. This reduces the capillary forces preventing oil from moving through rock pores. Other mechanisms of biosurfactants through

the formation of an emulsion by bind tightly to the oil-water interface, which stabilizes the desorbed oil in water and permits removal of oil beside the injection water (Mao *et al*., 2015)
Biosurfactants also increase the relative permeability of the reservoir to oil by the wettability alteration of the reservoir core to a more water-wet condition (De Araujo *et al*., 2019; Park *et al*., 2019). The present study aimed to test the biosurfactant produced by bacteria isolated from oil fields to improve oil recovery using a sand-packed column in vitro.

Material and method

Bacterial strains

The best two biosurfactants produced by *Bacillus cereus* ASWISA8 and *Enterobacter cloacae* FC1375 (Hamzah *et al*, 2020) have been tested for enhanced oil recovery usage sand-packed columns.

Oil recovery using sand packed columns

The sand-packed column was designed based on Suthar *et al.* (2008), with some modifications are illustrated in figures (1&2). Both ends of the column are sealed with rubber rings to pack the sand and prevent leakage during liquids injection. In the center of rubber, rings present holes at 3mm in size for insertion of tubes for injection and outflow of fluid. Approximately 200 g of acidic wash sand having a size of 1.5 mm was packed into the column. Other rubber rings put it up in the sand to prevent the sand grain from spreading through the liquid injection. All steps of experiment and derived equations according to (Salehi *et al.*, 2014; Ali *et al*., 2019). The first step, calculated sand volume (SV) in column (equation 1).

$SV= r^2 \pi h$ ……………………… (1)

r = radius, h=height

The column flooded with formation water under constant pressure (5 psi) to ensure its 100% saturation with water figure (2.c). Pore volume (PV) of the column was calculated by measuring the initial water volume (IBV) required to saturate the column then calculating porosity Eq. (2).

Porosity (%) = IBV/ PV × 100 …... (2)

The light oil was then flooded into the sand at a speed of 5 ml/min with constant pressure at room temperature to displace the water until no further water was discharged from the sand outlet figures (2.d and 2.e), the volume of discharged water represented the original oil in place (OOIP), then calculated the initial oil saturation (Soi) Eq. (3) .

Soi (%) = OOIP/ PV ×100 ……. (3)

The oil-saturated column was left for 48 hours. Allow the sand to change the wettability of the substrate to blend wet. Formation water was pumped into the column at a 10 ml/min velocity until there was no oil in the effluent figure (2 f.g.h). The volume of oil that could be recovered by waterflood (SorFW) was recorded, and the percentage rate of oil recovery (Swi) was calculated as follows: Equ (4).

Swi (%) =Volume of oil recovery by waterflood/ OOIP ×100………… (4)

The oil that could not be recovered by water flooding is termed as residual oil saturation (Sor) Equ (5) and was calculated as follows:

Sor (%) = OOIP-V.of oil recovery by waterflood/ PV×100 ….... (5)

After the water flooding, crude biosurfactant solution was then continuously flooded to recover more oil from the (Sor) figure (2.i). The volume of oil recovered (Sor FW) was recorded and additional oil recovered (AOR) due to crude biosurfactant was calculated Equ (6).

AOR (%) = Sorbf / OOIP-Sorwf ×100 (6)

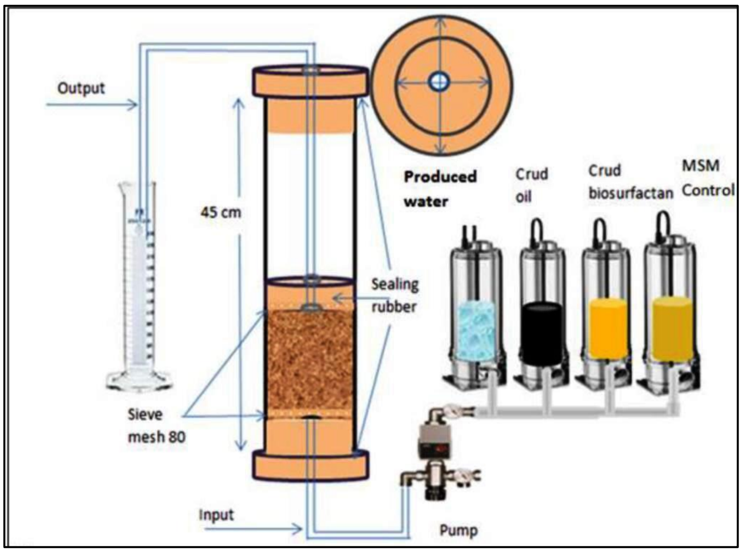

Figure 1: Schematic illustration of the sand-pack column model

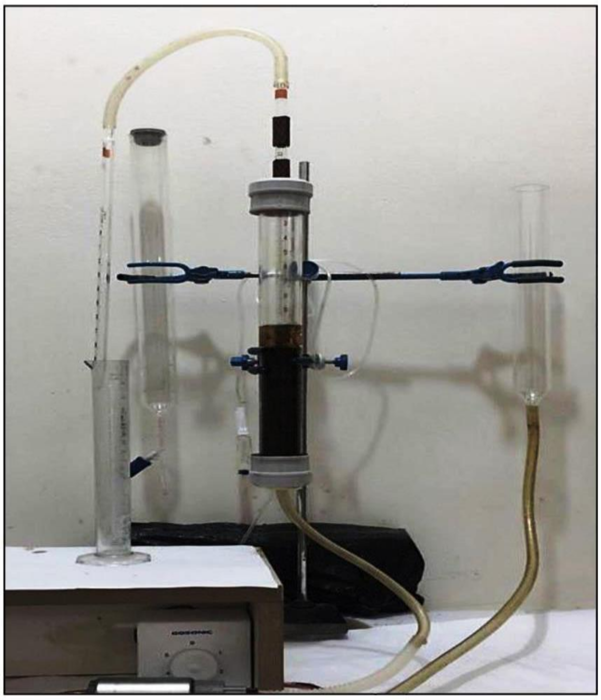

Figure 2: sand-pack column used for MEOR studies adapted of (Suthar *et al.*, 2008).

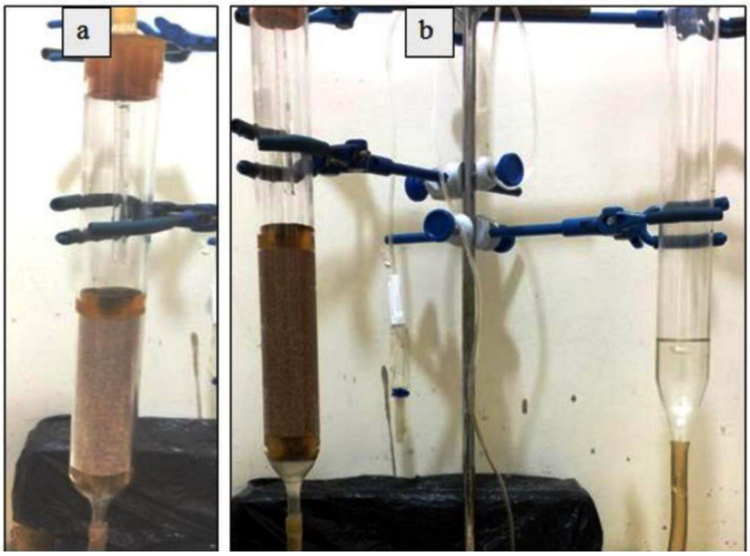

Figure 2: a- Packed the sand into a cylindrical glass column, b- The column flooded with formation water under constant pressure.

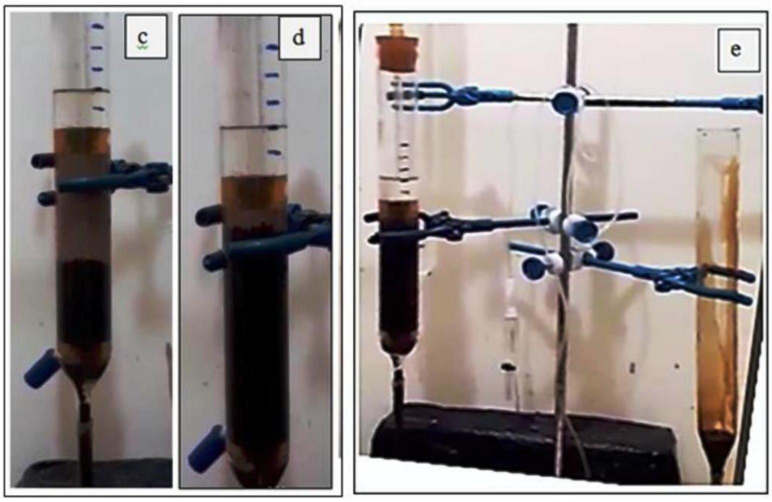

Figure 2(c, d &e): crude oil flooded into the sand

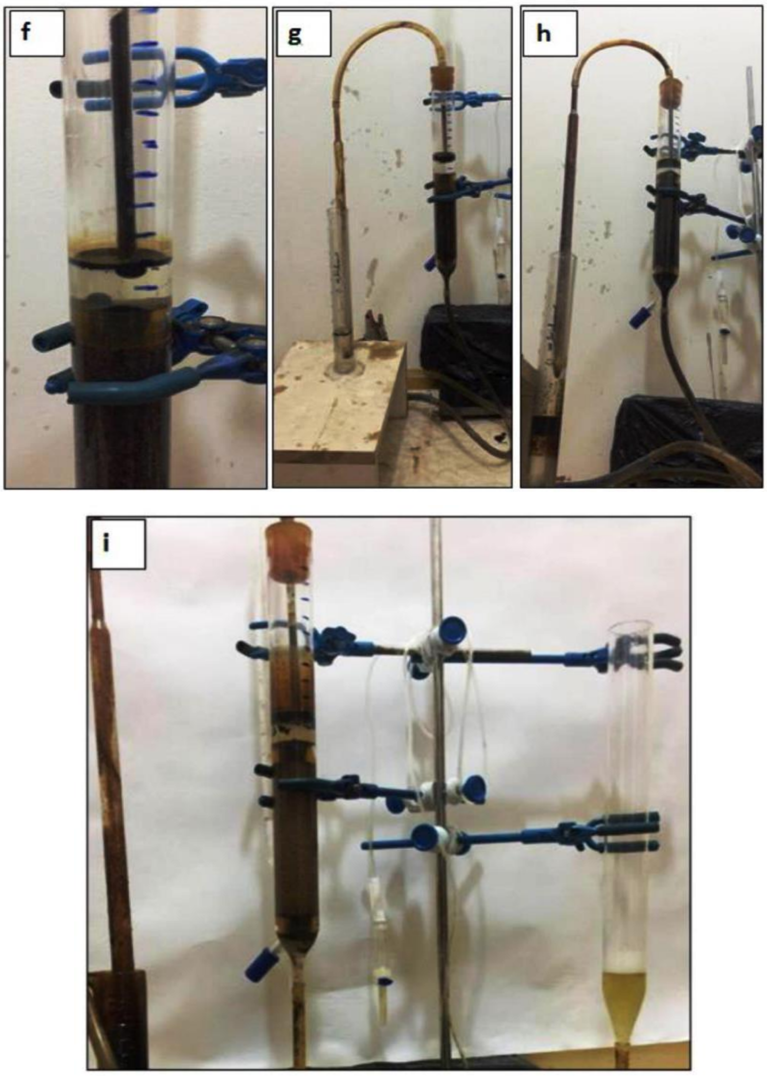

Figure 2(f-g-h): **Formation water pumped into the column, I- crude biosurfactant solution continuously flooded to recover more oil (Sor).**

Results

Oil recovery using sand packed columns

Table (1) Summarizes the results obtained in a sand-pack column for crude oil recovery using *Bacillus cereus* ASWISA8 and *Enterobacter aerogenes* B19.

Table (1) shows that *Bacillus cereus* ASWISA8 and *Enterobacter aerogenes* B19 strain can enhance oil recovery with the sand-pack column. The pore volume (PV) of the column is about 37.5-38 ml, OOIP (original oil in place) of the column is 32 ml and 33 ml, after the water flooding process, 39.47 % and 37.68 % of the oil remained trapped into the column 1 and column 2 respectively. When the biosurfactant of *Bacillus cereus* ASWISA8 was introduced into column 1 and incubated for 24 h at 35_{o}C, the amount of oil recovered after the biosurfactant flood was 3.8 ml. This means that additional crude oil was recovered (32.39%). In addition, when the biosurfactant *Enterobacter aerogenes* B19 strain was introduced into column 2 and incubated for 24 h at 35 $_{o}$C, the amount of oil recovered after biosurfactant flood was 4.6ml. This means that additional crude oil was recovered (25.33%), but the highly significant difference ($p \leq 0.05$)

compared with the additional oil recovery rate, which was recorded with the MSM medium as control.

Table 1: Summary of the results obtained in sand-pack column OOIP; original oil in place, Soi%; percentage of initial oil saturation, Swi; initial water saturation, Sor %: percentage of residual oil saturation, Sorwf: oil recovered after waterflooding, Sorbf : oil recovered after biosurfactant flooding AOR: additional oil recovery.

Parameter	*Bacillus cereus* ASWISA8 column 1	*Enterobacter aerogenes* B19 column 2	MSM control
Sand column volume	96	96.46	95.8
IBV= PV (ml)	37.5	38	37.2
Porosity %	39	39.3	38.8
OOIP (ml)	32	33	31.5
Soi (%)	85	86	84.6
Sorwf (ml)	17.8	18	17
Swi (%)	47.46	47.36	45.96
Sor (%)	37.68	39.47	38.97
Sorbf (ml)	4.6	3.8	0.6
AOR (%)	32.39	25.33	4.31

Discussion

Oil recovery using sand packed columns

The results of use biosurfactant to oil recovery using the Sand Pak Column method showed additional crude oil was recovered (32.39%) treated with F.C.S.B.sr. produced by *Bacillus cereus* ASWISA8 and (25.33%) treated with F.C.S.B.em produced by *Enterobacter aerogenes* B19 strain. Perfumo *et al*. (2010) explained the ability to oil recovery using biosurfactant by reducing the interfacial tension between water and oil, which altered the pore-rock wettability by changing the rock properties from oil-wet to water-wet, or oil emulsifying. Khire, (2010) indicated that the surface-active molecules (biosurfactant) will disperse oil parts in water through establishing a bridge between fluids with totally different polarities, like oil-water, by reducing free energy per unit space by forming micelles that are enclosed the oil droplets, and by increasing the oil solubilization in water.

The importance of the use of biosurfactant to improve oil recovery lies in its ability to reduce surface tension that enables the displacement of trapped oil from the porous medium. Displacement of oil trapped also may occur in overcome capillary forces by when sufficient reduction of the interfacial tension that facilitates the displacement of oil as well as the possibility of forming the emulsion that causes oil to be separated into water phases that facilitate its recovery (Sarubbo *et al*., 2015; Santos *et al*., 2016; De Almeida *et al*.,2016).

The results of the current study agreed with several studies that tested the ability of biosurfactant and bioemulsifier produced from various bacterial strains to oil recovery using the Sand Pack Column method, but with varying extraction rates. Bordoloi and Konwar (2008) used biosurfactants produced by *Pseudomonas aeruginosa* have been found to give 15% oil recovery in the sand pack column. Suthar *et al*. (2008) tested bioemulsifier produced by *Bacillus licheniformis* strain K125, to enhance oil recovery using sand pack column method they showed 43 % additional oil recovery. Similar results were observed by isolate *Bacillus subtilis* MTCC 2422 strain that potential to produces an effective biosurfactant showed 36% of oil recovery mN/m (Kanna *et al*., 2016). Qazi *et al*. (2013) used a sand pack column to test crude biosurfactant produced by *Fusarium sp.*

The result was 38% of the oil recovery. Gudiña *et al*. (2015) indicated that the three *Bacillus subtilis* strains isolated from crude oil samples were tested using a sand-pack column model, which was designed to simulate oil recovery operations and evaluate mobilization of residual oil by the selected strains gave additional oil recoveries recorded ranged from 6 to 24% .

El-Sheshtawy *et al*. (2016) compared between biosurfactant produced by *Bacillus licheniformis* and *Candida albicans* introduced into two sand-pack column the oil recovery rate were (16.6%) ,(8.6%) respectively, they concluded that bacterial biosurfactant is more efficient than biosurfactant produced from yeast. Zhao *et al*. (2018) used indigenous biosurfactant produced by *Pseudomonas aeruginosa* for core flooding tests revealed that an extra 5.22% of the oil was displaced. Joshi *et al*.(2019) reported Sophorolipids biosurfactant produced by *Candida bombicola* ATCC 22214 was further used in MEOR experiments using oil reservoir core-plugs where it showed additional 9-13% extra oil recovery.

Conclusion

Some bacterial isolates isolated from oil fields have the ability to produce surfactants and emulsifiers that can be used in enhanced oil recovery processes. In this study, the surfactant produced from isolate *Bacillus cereus* ASWISA8, and the emulsion produced from isolate *Enterobacter aerogenes B19* were tested in oil recovery processes using sand packed column. The additional oil recovery rate (32.39%) was recorded when treated with cell free supernatant containing biosurfactants produced from *Bacillus cereus* ASWISA8 and (25.33%) using cell free supernatant containing the bio-emulsion produced from *Enterobacter aerogenes B19.*

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تحسين استخراج النفط في عمود الرمل المضغوط باستخدام عوامل خافضة للتوتر السطحي تنتجها بكتيريا معزولة من حقول نفط محلية

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المستخلص

في هذه الدراسة ، تم استخدام مواد خافضة للتوتر السطحي خالية من الخلايا (منزوعة الخلايا) لعزلتين مختارتين من سلالة *Bacillus cereus* ASWISA8 وسلالة *Enterobacter aerogenens* B19 لاستخراج النفط بواسطة عمود الرمل المضغوط والذي تم تصميمه لاختبار تحسين اعادة استخراج النفط عن طريق حساب حجم الرمل (SV) ، المسامية ، التشبع الأولي بالنفط (Soi) ، معدل النسبة المئوية لاستخلاص النفط (Swi) ، النفط المشبع المتبقي (Sor) ، حيث تم تسجيل حجم النفط المستخرج بواسطة مياه التكوين (Sor FW) والنفط الإضافي (AOR) المستخرج باستخدام مواد خافضة للتوتر السطحي. أظهرت النتائج أن الزيت الخام الإضافي تم استخراجه عند حوالي (32.39٪) عند معاملته بطافي منزوع الخلايا الحاوي مواد خافضة للتوتر السطحي المنتج من العزلة *Bacillus cereus* ASWISA8 و (25.33٪) باستخدام الطافي منزوع الخلايا الحاوي على المستحلب الحيوي المنتج من العزلة *Enterobacter aerogenes* B19.