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Full Length Research Paper

Enhancement of recovery of residual oil using a biosurfactant slug

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A laboratory investigation of the mobilization and displacement of residual oil in a sand-pack using biosurfactant slug was conducted. The biosurfactant employed was extracted from a culture of *Pseudomonas* sp. grown on kerosine- supplemented mineral salts medium. Characterization of the biosurfactant extract revealed a mixture of glycolipid and phospholipid in a ratio of 3.35:1. The irreducible water saturation (S_{wi}) and initial residual oil saturation (S_{or}) of the sand-pack were 0.280 ± 0.003 and 0.373 ± 0.006, respectively. Core flooding experiment showed that an optimum oil recovery of 52.19% of the in-place residual oil was achieved at biosurfactant incubation time (BIT) of 120 h. These results suggest that biosurfactant produced by Pseudomonas species is a potential "candidate" for microbially enhanced oil recovery.

Key words: Laboratory investigation, enhanced oil recovery, biosurfactant slug, *Pseudomonas* species.

INTRODUCTION

The importance of energy in determining the social stability and economic viability of a nation is enormous. Crude oil, the world's major source of energy, is essentially a mixture of compounds formed from hydrogen and carbon, although they may contain traces of nitrogen, sulfur, nickel and vanadium (Paul and Ladd, 1981).

The process of drilling oil from the rock formation (reservoir) is called the recovering process. Petroleum is initially forced out or recovered, naturally, as a result of pressure in the reservoir and this is referred to as primary recovering phase (Berger and Anderson, 1992). This natural recovery is followed by enhanced oil recovery (EOR) process. When the EOR process involves the injection of water (or gas) it is called secondary recovery, and tertiary recovery if it involves the use of heat, chemical, miscible displacement and microbial products, etc (Moses, 1987; Donaldson et al., 1985).

Microbial EOR has been a technology of interest and the topic of a number of review articles and international conferences (Bryant et al., 1990; Moses and Springham, 1982; Rosenberg, 1986). Microbially enhanced oil recovery (MEOR) involves the application of microbes and/or the exploitation of microbial metabolic processes and products to increase the production of residual oil reservoir (Finnerty, 1992). A bioproduct that has been widely employed in the oil industry is xanthan gum produced by Xanthomonas campestris (Baird et al., 1983). A number of in situ MEOR has been reported and reviewed, although in small stripper wells (Moses and Springham, 1982; Yarborough and Coty, 1983; Bryant et al., 1990). Despite the short-coming and limitations of in situ MEOR technology, the production of biosurfactant by diverse microflora has been implicated to explain some of the effects and mechanisms involved in the observed oil displacement. This paper presents results of a laboratory investigation of the mobilization and displacement of residual oil in a sand-pack (a microcosm of an oil formation) using biosurfactant slug.

MATERIAL AND METHODS

Biosurfactant production and analyses

Exactly 950 ml mineral salts medium of Mill et al. (1978) as modified by Okpokwasili and Okorie (1988) supplemented with kerosene (0.3%, w/v) as carbon source was employed. The medium was composed thus: $MgSO_4.7H_2O$, 0.42 g/l; KH_2PO_4, 0.83 g/l; Na_2HPO_4, 1.25 g/l; KCl, 0.29 g/l; and NH_4NO_3, 0.42 g/l. The medium was adjusted to pH 7.2 and sterilised at 121°C and 15 psi for 15 min. This was, then, inoculated with 50 ml of 3-day old culture of *Pseudomonas* sp. (0.1% w/v kerosene-mineral salts

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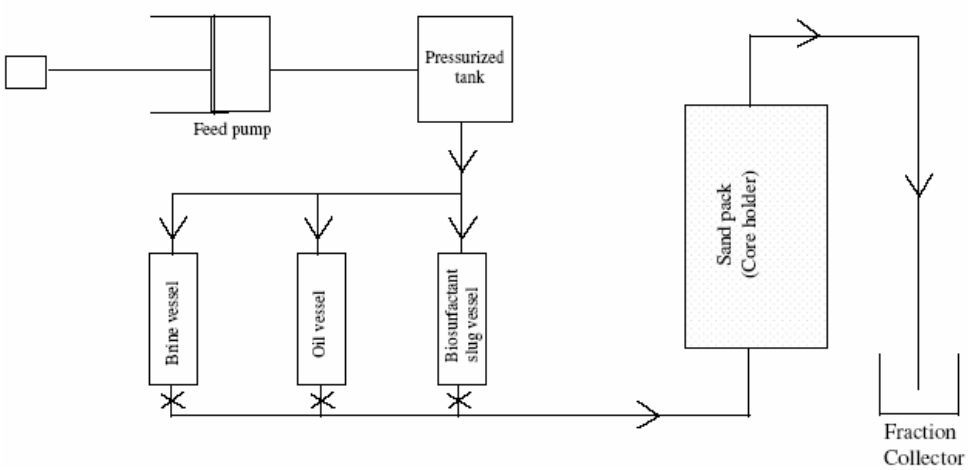

Figure 1. Experimental set–up for coreflooding.

Table 1. Characteristics of biosurfactant extract.

No.	Analyse	Observation	Tentative Class	Concentration (ppm)
1	Anthrone	+	Glycolipid	670
2	Phosphate	+	Phospholipid	200

+ = Positive.

medium) and incubated at room temperature for seven days. The production culture was sampled and centrifuged at 3000 rpm for 15 min. The supernatant fluid was decanted and filtered immediately through whatman No. 1 filter paper. The resultant filtrate was employed as the biosurfactant slug.

The crude biosurfactant was extracted with chloroform and characterised using the anthrone and phosphate test methods (Gerhart et al., 1981). The concentrations of sugar and phosphate in the extract were determined from standard calibration curves prepared by plotting absorbance of the standard glucose and phosphate solutions versus their respective standard concentrations.

Experimental set-up for core flooding

The experimental set-up was constructed with glass material. Schematic diagram of the set-up is shown in Figure 1. It consists of a core-holder (containing unconsolidated sand of grain size and porosity 300–426 µm and 0.309 ± 0.008, respectively), three chemical reservoirs, pressurized tank and foot pump. The core-holder is 2.2 cm in diameter (internal) and 9.5 cm in height (effective height). The three chemical reservoirs for brine (10%, w/v NaCl), biosurfactant slug, and crude oil (Bonny light) are 250 ml capacity each. The pressurized tank and the foot pump served as the pressure source to force fluids up the core-holder containing the sand sample.

Core flooding/residual oil displacement experiment

The sand sample (unconsolidated) in the core-holder was saturated with brine (about 1.0 pore volume). The brine saturated sand pack was then flooded with the crude oil until approximately zero water cut in effluent was obtained and the irreducible water saturation (S_{wi}) was determined. Immediately, brine flooding commenced until initial residual oil saturation (S_{or}) was reached and determined. The core was, then, saturated with about 1.5 pore volume of the biosurfactant slug and followed by “chase” brine flooding until no more oil was produced. This served as the zero hour biosurfactant incubation time (BIT) production. The experiment was repeated for BIT of 24, 48, 72, 96 and 120 h. The final residual oil saturated (S_{orc}) and percentage recovered after biosurfactant slug saturation and subsequent “chase” brine flooding for 0, 24, 48, 72, 96 and 120 h were determined.

RESULTS AND DISCUSSION

The result of the chemical analyses of the biosurfactant extracted with chloroform is shown in Table 1. It indicated positive for both anthrone and phosphate tests. This reveals the presence of sugar and phosphate groups hence glycolipid and phospholipid, respectively.

Colorimetric measurement and subsequent extrapolation of the concentration of sugar and phosphate from standard calibration curves reveals that the biosurfactant extract contained 670 ppm of sugar and 200 ppm of phosphate. Therefore, glycolipid and phospholipid contents of the crude biosurfactant are in a ratio of 3.35:1. A number of glycolipid-type biosurfactants have been reported including rhamnolipid, tetrahalose dimycolate, tetrahalolipids among others (Syldatk et al., 1985; Singer et al., 1990).

Table 2. Core flooding Characteristics

No.	Parameter analysed	Values (mean ± standard error)
1	Irreducible water saturation (S_{wi})	0.280 ± 0.003
2	Initial residual oil saturation (S_{or})	0.373 ± 0.006
3	Final residual oil saturation (S_{orc})	0.193 ± 0.010

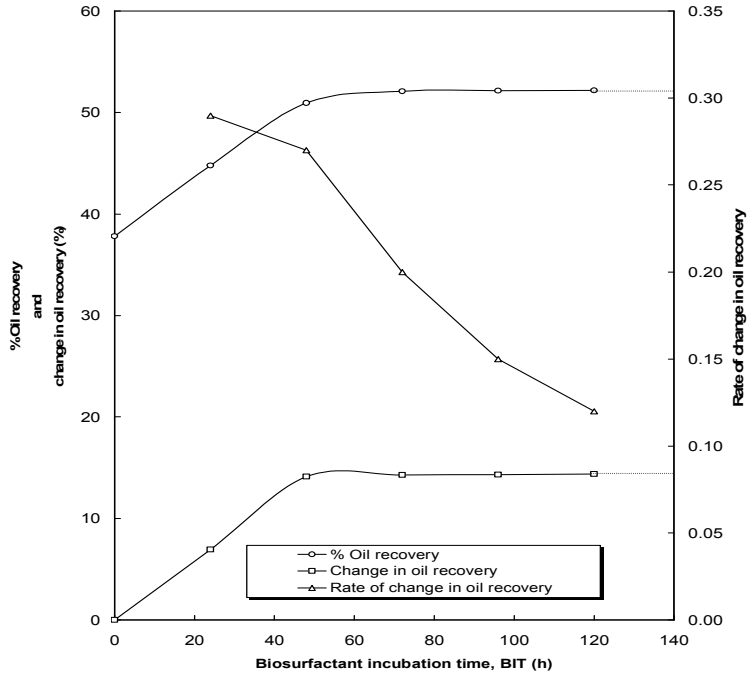

Figure 2. Oil recovery profile

Table 2 presents the results of core flooding experiment. It shows that the irreducible water saturation (S_{wi}), initial residual oil saturation (S_{or}) and final residual oil saturation (S_{orc}) are 0.280 ± 0.003, 0.373 ± 0.006 and 0.193 ± 0.010, respectively. These indicate an initial oil saturation of (1-S_{wi}) which was reduced to a saturation of 0.373 after the brine flooding.

Figure 2 presents the oil recovery profile in terms of the percentage oil recovery (R) and change in percentage oil recovery (ΔR) versus BIT. The R-BIT curve shows that an initial oil recovery of 37.82% of the residual oil was obtained following "chase" brine flooding at zero hour BIT. As the BIT was increased to 24 h, a relatively sharp increase in oil recovery (about 44.78%) was obtained. Thereafter, relatively small increases through 120 hour BIT when 52.19% was recovered (maximum recovery over the study period). The change in percentage oil recovery versus BIT curve shows that small increases of percentage oil recovery were obtained with increasing BIT though not proportional, and the incremental oil recovery with increase in time (BIT), approaches zero, beyond 120 h. This is depicted by the dotted line extrapolations of both curves, which is horizontal to the BIT axis. The rate of change in percentage recovery, also, shows that the rate of recovery decreased with increase in times. The observed recovery or mobilization of the residual in-place oil by the biosurfactant slug indicates its ability to alter the wettability of the sand particles and the reduction of interfacial tension. A practical method of raising the capillary number for the reservoirs to give improved recovery is by reducing the interfacial tension to very low values (Du Prey, 1973; Foster, 1973). Wettability control has been proposed as a method of enhanced recovery though the subject is not well developed (Morrow and Heller, 1985).

Although Nigeria is endowed with a great number of oil reserves yet to be exploited, and has not reached marginal oil productivity, potential application has been indicated for bioproducts in microbially enhanced oil recovery (MEOR) as revealed by this study. However, field trials need to be carried out since laboratory data alone cannot always, with accuracy, be extrapolated to full-scale operations without field validation.

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