JPIChE 51 (2) 2023: 11-18

PAKISTAN INSTITUTE OF CHEMICAL ENGINEERS
Since 1969

Journal of Pakistan Institute of Chemical Engineers

journal homepage: www.piche.org.pk/journal

DOI: https://doi.org/10.54693/piche.05122

Check for updates

Experimental Study of Enhanced Oil Recovery by Surfactants using Core Flooding

A.S.A. Shahid[1,2], M.K. Zahoor[1], M.A. Khan[1,3], F. Mehmood[1] M. Haris[1]*

Submitted: 06/02/2023, Accepted: 27/10/2023, Online: 31/10/2023

Abstract

Viscous and capillary forces are the main cause of unwept oil remaining in the pores of the reservoir after two stages of recovery, i.e., primary, and secondary. Proper application of the EOR technique can enhance the life of the reservoir. Surfactants are specially prepared chemicals that reduce the interfacial or surface tension between fluids. The objective of this study is to select the surfactant that gives maximum recovery in core flooding experiments. Different porosity core samples were prepared artificially using cement and sand in the laboratory and saturated with diesel in a manual saturator apparatus. Surfactant flooding experiments were conducted using five different surfactants, i.e., Lutensol TO-3, Lutensol XP-50, Lutensol XL-70, SLS, and SLES. After collecting the data from experiments, the graphs of the comparison of oil recovery for different porosity samples with the base case, i.e., water flooding, are presented. From experimental results, it shows that all five surfactants that I have used in my core flooding experiments give an increase in recovery compared to water flooding. The experimental results show that up to 78% of OIIP can be extracted. Lutensol TO-3 gives maximum recovery for low-porosity core samples, i.e., about 20% more than water drive. Sodium Lauryle Ether Sulfate (SLES) gives maximum recovery for high-porosity core samples, i.e., about 23% more than water flooding. From these five surfactants, Sodium Lauryle Ether Sulfate (SLES) (anionic) is selected for maximum recovery of the reservoir for this chemical EOR.

Keywords: Enhanced Oil Recovery, Experimental, Surfactant Flooding, Sodium Lauryle Ether Sulphate.

1. Introduction:

The focus of most companies is to maximize the recovery factor of the existing fields within the economic limit, given the uncertainty involved in the investments for the discovery of new fields [1]. The life of a production well normally comprises three production stages, i.e., primary, secondary, and tertiary recovery. In primary recovery, hydrocarbons are produced by the natural energy of the reservoir, i.e., water drive, gravity drainage, or gas drive. In secondary recovery, water or gas is injected through injection wells having communication with production wells located in the same reservoir to enhance the production of hydrocarbons by maintaining pressure, as space vacated by produced fluids is occupied by these injected fluids [2]. The average recovery factor (RF) for a mature field is about 20–40% of the oil originally in place (OOIP) of the reservoir for this pressure maintenance technique. For shale gas reservoirs even the petrophysical properties are so weak, with smaller pore network systems [3] that it makes production even more difficult. Tertiary or enhanced oil recovery (EOR) is a set of methods or techniques in which external energy or materials are injected into the reservoir. The main purpose of EOR is to alter the wettability, interfacial

[1] *Department of Petroleum and Gas Engineering University of Engineering and Technology Lahore, Pakistan.*
[2] *Department of Energy and Mineral Resource Engineering, Sejong University, Seoul, South Korea.*
[3] *Department of Petroleum and Gas Engineering University of Chakwal, Chakwal, Pakistan.*
***Corresponding Author:** arshad.shahid@uet.edu.pk

tension (IFT), fluid properties, and pressure drawdown to overcome the holding forces and sweep the crude oil toward the production well in a controlled manner [4],[5],[17]. To achieve this formation evaluation using multiple sources is needed beforehand, wireline formation testing (WFT) [16] is one of the fasting ways to measure desired formation properties including fluid analysis. In general, three types of EOR techniques are used: gas injection, thermal recovery, and chemical injection [6]. In chemical injection EOR, two types of chemicals are injected, i.e., surfactants and polymers. Surfactants are specially prepared chemicals that reduce the interfacial tension or surface tension between fluids, i.e., gas-liquid and liquid-liquid, or between solids and fluids [7]. In this EOR technique, surfactants interact with molecules of residual oil to lower the interfacial tension and enhance sweep efficiency [6].

Surfactants are classified by how they act in solution form; these are classified into three groups, i.e., anionic, cationic, and nonionic, based on the nature of the head group. Anionic surfactants form positive and negative ions after dissolving in water; they are very common in EOR processes. They are good at lowering IFT, relatively stable, less absorbed in rock, and economical [6]. Non-ionic surfactants neither form anions nor cations in water; they are made of covalently bonded oxygen hydrophilic groups connected with hydrophobic structures. The hydrophilic part of these surfactants dissolve water because of hydrogen bonding [8]. Cationic surfactants form hydrophilic cations and hydrophobic anions in the solution. These surfactants require high pressure to undergo reactions in the subsurface. That's why they are more expensive to use than anionic and nonionic surfactants [6]. This study involves the flooding of different surfactants in artificially prepared core samples of sandstone to check the effect and performance of sensitivity analysis and to give an optimized solution of flooded surfactants on oil recovery. This study is very helpful in designing the surfactant flooding process for oil and gas reservoirs that is targeted to increase the productivity of the reservoir, thereby increasing the ultimate recovery.

2. Surfactants used in Experiments:

2.1. Lutensol Xp-50:

The Lutensol XP-50 is a non-ionic surfactant. This is a cloudy liquid at room temperature, and it tends to form sediment. It becomes clear at 50 °C. It is hygroscopic due to its good solubility in water and forms homogenous emulsions.

It is alkyl polyethylene glycol ether based on ethylene oxide and C10 Guerbet alcohol. The formula of this surfactant is:

$$C_{10}H_{21}(CH_2CH_2O)_5H$$

The Lutensol XP-50 is manufactured by causing the C10-alcohol to react with the ethylene oxide in the stoichiometric proportions. The degree of ethoxylation is five for this product [9].

2.2. Sodium Lauryl Sulphate (SLS):

It is an anionic surfactant. There are various names for this chemical in literature; another name that is widely used is sodium dodecyl sulphate. It is commercially available in white powder form. SLS is derived from palm and coconut oils. It is a synthetic-organic compound used in various hygiene and cleaning products [10]. The formula of this surfactant is:

$$CH_3(CH_2)_{11}SO_4Na$$

2.3. Lutensol TO-3:

This is a non-ionic surfactant. This is a cloudy liquid at room temperature, and it tends to form sediment. It becomes clear at 50 °C. It is hygroscopic due to its good solubility in water and forms homogenous emulsions. It is made from saturated iso-C13 alcohol. The formula of this surfactant is:

$$C_{13}H_{27}O(CH_2CH_2O)_3H$$

The degree of ethoxylation is three for this product. The Lutensol TO-3 is manufactured by causing the iso-C13 oxo alcohol to react with the ethylene oxide in the stoichiometric proportions [11].

2.4. Sodium Lauryl Ether Sulfate (SLES):

It is an anionic surfactant used in various personal care items i.e., soaps, toothpaste, shampoo etc. It is inexpensive and very good foaming agent. It is clear viscous or smooth thick paste.

through the ethoxylation of dodecyl alcohol. This dodecyl alcohol is derived from coconut oil or palm kernel oil. The The formula of this surfactant is:

$$CH_3(CH_2)_{11}(OCH_2CH_2)_3SO_3Na$$

SLES is produced produced ethoxylate is converted to a half-ester of sulfuric acid. After that, it is converted to sodium salt for neutralization. SLES is the ethoxylation of SLS; with the addition of ethylene oxide, the chemistry of SLS changes [10].

2.5. Lutensol XL-70:

Lutensol XP-70 is a non-ionic surfactant. It is a cloudy liquid at room temperature, and it tends to form sediment. It becomes clear at 50 °C. It is an alkyl polyethylene glycol ether based on ethylene oxide and C10 Guerbet alcohol and ethylene oxide. It contains higher alkylene oxides in slight amounts. The formula of this surfactant is:

$$C_{10}H_{21}(CH_2CH_2O)_7H$$

The degree of ethoxylation is five for this product [12].

3. Methodology:

Different porosity core samples are prepared artificially by using sand and cement in various ratios [13], [14]. The core samples are saturated with diesel by using manual saturator. The core samples are lowered into saturation cell by placing those in wire basket and then sealed with threaded plug. Vacuum pump is connected to the system and all the air and liquid is removed from the system by application of high vacuum for several hours. With the help of manual pump, the system is pressurized. It is assured that applied pressure should sustain for several hours by noting the readings on manometer for the maximum saturation of the core. LiquidPerm apparatus along with core-holder is used for surfactant core flooding experiments. The pressure of gas supply fluid from reservoir to core holder containing core with constant pressure. Fluids pass through core sample placed in core holder collected in graduated flask, volume of collected sample is noted [15].

The step wise procedure is as follows:

Water is injected into the core saturated with oil from one side, and oil is swept through the other side of the core, which is collected in the test tube. The volume of water and oil collected in this experiment is measured. After this step, the oil remaining in the core is irreducible oil. A proper calculation of the remaining oil is done based on the initial oil saturations and porosity of the cores. After the above-mentioned step, surfactant is injected into the core, which, extracts the trapped oil in the pores of the core and form a continuous phase to move by reducing interfacial tension (IFT) between oil and water droplets. Fluids pass through the core sample placed in the core holder and collected in a graduated flask. The volume of the collected sample is noted. Calculations for oil extracted by the surfactant are done, continuing from the previous steps. The above-mentioned steps are repeated for different surfactants. After the results collected from surfactant flooding experiments are presented, an optimised solution is presented.

3.1. Schematics of Core Flooding Experiments:

a. Connect the apparatus to the main supply and allow the pressure transducers to warm up for some time before use. The source valve should be switched to the off position, and all regulators should be fully anti-clockwise initially.

b. Connect the two gas supplies with the apparatus at specific points, i.e., one with the confining pressure gas supply at the confining section of the apparatus and the other to the fluid transfer vessel. Initially, run the apparatus with the fluid in the vessel without applying confining pressure; this makes the core holder parts wet the fluid.

c. Load the core sample into the core holder. Regulate the confining pressure and inlet pressure from the gas supplies. I have used 100 psi confining pressure and 40 psi inlet pressure. Note the readings.

d. After the completion of the experiments, release the confining pressure and inlet pressure. The core sample is removed from the core holder [15].

e. Figure 1 shows the schematics of the core

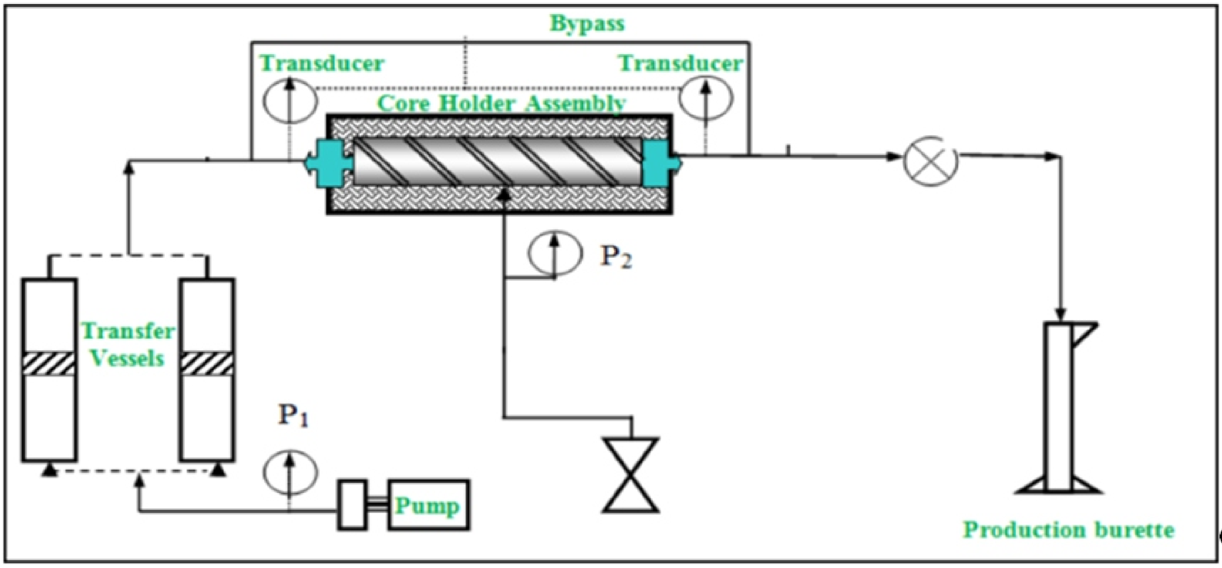

Figure 1: Schematics of core Flooding experiments

4. Results and Discussion:

The porosity and permeability of core samples are determined using manual saturator and liquid permeameter apparatuses, respectively. The data is presented in tables 1 and 2.

Table 1 : Porosity determination of the core samples

Sr. #	Sample Ratio	Dry wt. (kg)	Saturated wt. (kg)	Length (m)	Diameter (m)	mass dif (kg)	Oil Vol. in Pores (ml)	Pore Volume m^3	Area of core m^2	Volume of core m^3	Porosity (%)
1	01:02	0.155	0.181	0.076	0.039	0.026	30.6	3.1E-05	0.0012	9.1E-05	33.7
2	01:04	0.141	0.172	0.076	0.039	0.031	36.5	3.6E-05	0.0012	9.1E-05	40.2
3	01:06	0.134	0.167	0.076	0.039	0.033	38.8	3.9E-05	0.0012	9.1E-05	42.8
4	01:08	0.129	0.165	0.076	0.039	0.036	42.4	4.2E-05	0.0012	9.1E-05	46.7

Table 2: Permeability determination of the core samples

Sr. #	Sample Ratio	Dia (mm)	Length (mm)	Flask volume (cc)	Time		Pressure (psi)		Fluid viscosity (cp)	K (mD)
					(min)	(s)	atmospheric pressure	Inlet pressure		
1	01:02	390	760	100	3	15	14.7	40	1	19.0
2	01:04	390	760	100	0	35	14.7	40	1	105.6
3	01:06	390	760	100	0	16	14.7	40	1	231.0
4	01:08	390	760	100	0	10	14.7	40	1	369.5

4.1. Percentage Recovery:

The figure 2 represents the percentage increase in the Porosity of the core samples after treatment by different types of surfactants.

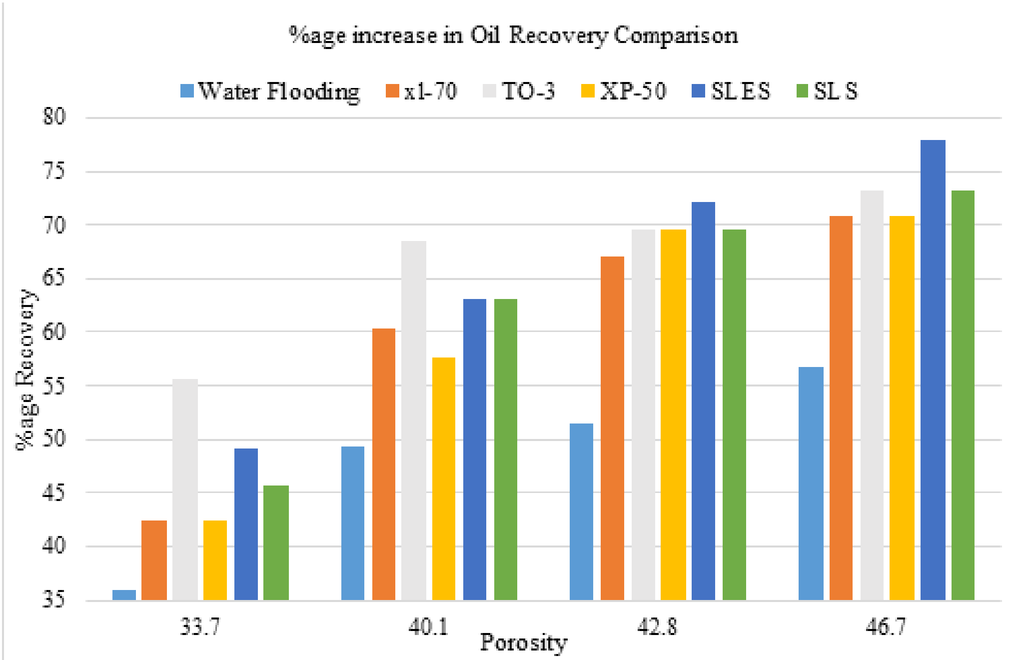

Figure 2: Comparison of % age recovery by water and surfactants flooding

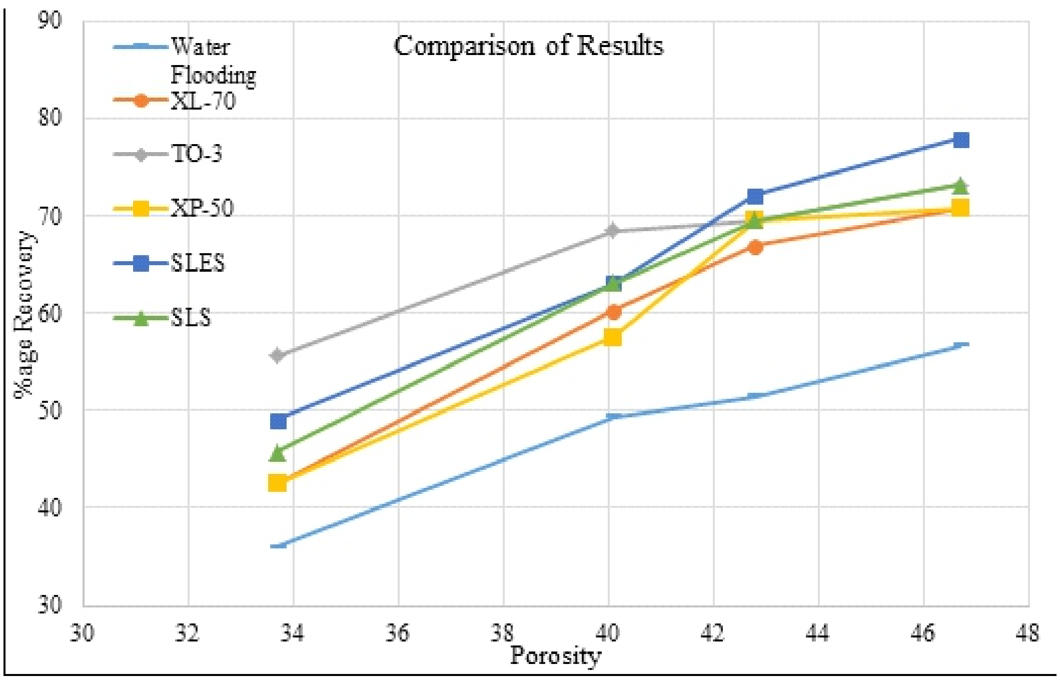

Figure 3: Comparison of results

Figure 3 shows the results obtained in core flooding experiments for different porosity core samples. Figure 3 shows the comparison of oil recovery by different surfactants for individual porosity values.

* For a 33.7% porosity core sample. As the graph shows, all the surfactants give an increase in the percentage recovery of oil compared to water flooding. For this porosity, Lutensol TO-3 surfactant gives maximum recovery.
* For a 40.1% porosity core sample. As the graph shows, all the surfactants give an increase in the percentage recovery of oil compared to water flooding. For this porosity, Lutensol TO-3 surfactant gives maximum recovery.

For this porosity, Lutensol TO-3 surfactant gives maximum recovery.

* For a 42.8% porosity core sample. As the graph shows, all the surfactants give an increase in the percentage recovery of oil compared to water flooding. For this porosity, SLES surfactant gives maximum recovery.

* For a 46.7% porosity core sample. As the graph shows, all the surfactants give an increase in the percentage recovery of oil compared to water flooding. For this porosity, SLES surfactant gives maximum recovery.

Figure 3 presents a comparative graph of recovery behavior for all the surfactants that were used in the experimentation. From this line graph, we can check the approximate recovery of the particular surfactant at any porosity range.

4.2. Fractional Flow of SLES:

Table 3: Fractional Flow of SLES for different porosity samples

Porosity	Vol. of flask (ml)	Oil vol (ml)	Sur. Vol (ml)	time (sec)	fo	So	Porosity	Vol. of flask (ml)	Oil Vol. (ml)	Sur. Vol. (ml)	time (sec)	fo	So
33.7	25	7	18	60	0.28	0.73	42.8	25	18	7	8	0.72	0.54
	25	5	20	65	0.20	0.61		25	5	20	11	0.20	0.41
	25	2	23	72	0.08	0.54		25	4	21	14	0.16	0.31
	25	1	24	80	0.04	0.51		25	1	24	15	0.04	0.28
40.1	25	14	11	20	0.56	0.62	46.7	25	22	3	6	0.88	0.48
	25	5	20	23	0.20	0.48		25	6	19	8	0.24	0.34
	25	3	22	27	0.12	0.4		25	3	22	9	0.12	0.27
	25	1	24	32	0.04	0.37		25	2	23	11	0.08	0.22

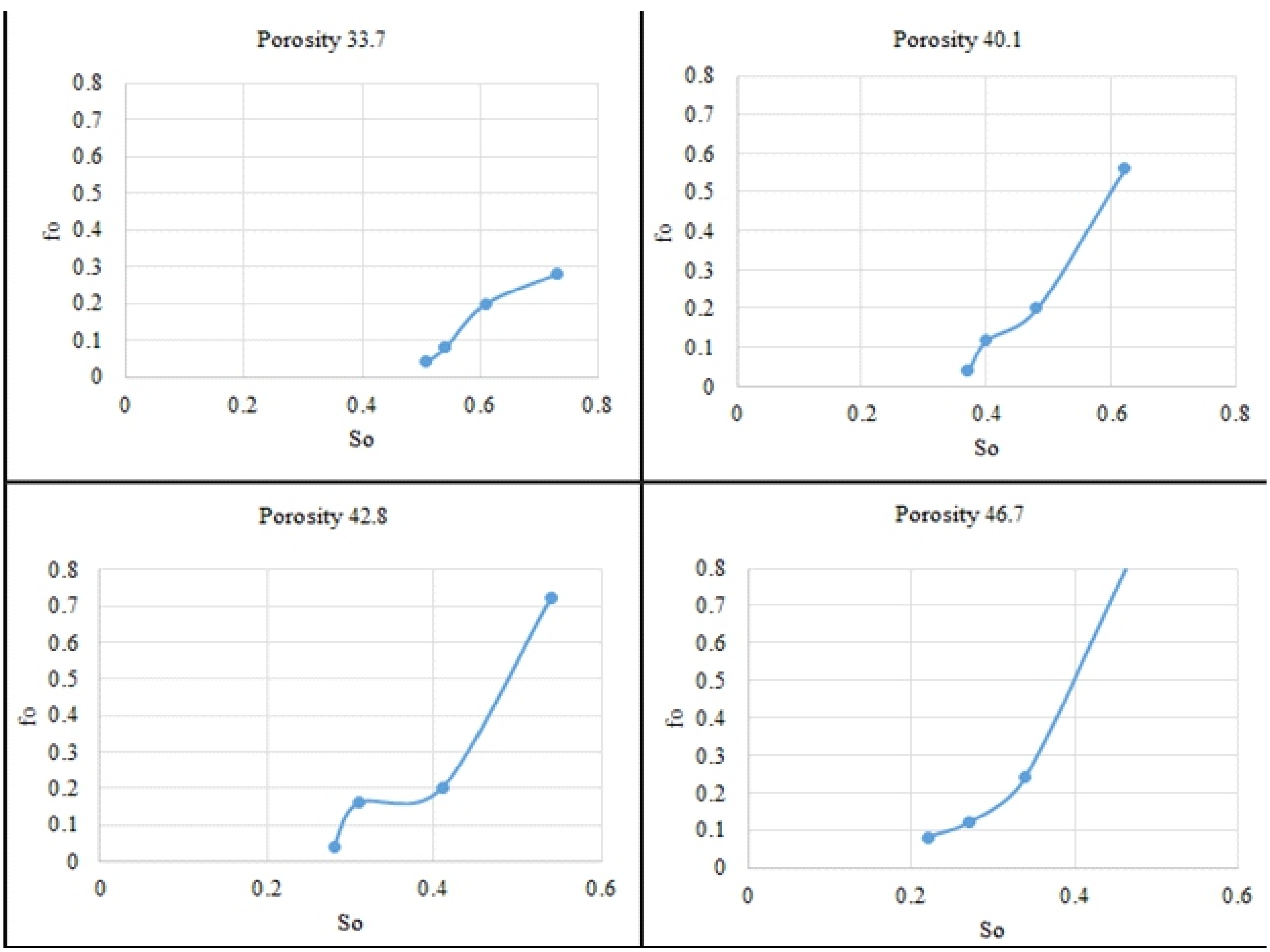

Figure 4: Fractional Flow of SLES for different porosity samples

The results of the fractional flow of SLES for different porosities are presented in Table 3. The fractional flow graph is presented in figure 4. This surfactant flooding is performed by collecting the fluid in a 25-ml flask at four intervals for each porosity core sample. The volume of oil and surfactants is noted in the graduated flask after the settlement of fluids due to gravity. For low-permeability core samples, a significant amount of oil remains in the pores of the sample as the pores are not interconnected. The results show that most of the oil was swept during the first half of the recovery period. In the next half, the surfactant cut is significant as compared to the oil cut.

5. Conclusions:

In the results section, the following conclusions are drawn from this study:

- All five surfactants that have been used in core flooding experiments give an increase in recovery compared to conventional water flooding.
- Lutensol TO-3 gives maximum recovery for a low-porosity core sample, i.e., about 20% more than water flooding.
- Sodium Lauryle Ether Sulfate (SLES) (anionic) gives maximum recovery for a high-porosity core sample, i.e., about 23% more than water flooding.
- From these five surfactants, sodium lauryl ether sulphate (SLES) (anionic) is the best candidate for maximum recovery of the reservoir for this chemical EOR. It is based on its performance and availability as compared to other surfactants used in this study.

6. Recommendations:

The following work is recommended: Check the effect of different concentrations of the surfactant on the recovery. Calculate the cost of chemicals to produce a barrel of oil ($/bbl). efficiency of surfactant, i.e., surfactant needed to produce a barrel of oil (lb/bbl oil). Surfactant absorbed or lost in flooding experiments.

References:

1. I. Sandrea, "Recovery factors leave vast target for EOR technologies," Oil & Gas Journal, vol. 105, no. 16, pp. 32-36, 2007.
2. M. Muskat, Physical Principles of Oil Production. New York City: McGraw-Hill Book Co. Inc., 1949.
3. H.-M. Kim, M. V. Abbas, M. Shoaib, N. A. Alshmlh, and A. S. Ahmad Shahid, "Analytical models for gas production in a shale reservoir: A review focusing on pore network system," Journal of the Pakistan Institute of Chemical Engineers, vol. 49, no. 2, pp. 47-58, 2021.
4. K.S. Sorbie, Polymer-Improved Oil Recovery. Glasgow: Blakie, CRC Press, 1991.
5. A.R. Kovscek and H. W. Wong, "Microvisual investigation of polymer retention on the homogeneous pore network of a micromodel," Journal of Petroleum Science and Engineering, vol. 135, pp. 115-127, 2015.
6. D.W. Green and G. P. Willhite, Enhanced Oil Recovery. Texas: SPE Text Series, 1998.
7. A.K. Flaaten and Q. P. Nguyen, "A systematic laboratory approach to low cost, high-performance chemical flooding," SPE Reservoir Evaluation & Engineering, vol. 11, no. 5, pp. 713-723, 2008.
8. K. Kosswig, "Surfactants," in Ullmann's Encyclopedia of Industrial Chemistry, Weinheim: Wiley-VCH, 2005.
9. BASF, Technical Information of Surfactants Lutensol XL types. Ludwigshafen, Germany: BASF, 2003.
10. J.M. Liebert, "Final Report on the Safety Assessment of Sodium Laureth Sulfate and Ammonium Laureth Sulfate," Journal of the American College of Toxicology, vol. 2, no. 1, pp. 1-34, 1983.
11. BASF, Technical Information of Surfactants Lutensol TO types. Ludwigshafen, Germany: BASF, 1997.
12. BASF, Technical Information of Surfactants Lutensol XP types. Ludwigshafen, Germany: BASF, 2003.

13. J. Qishun, The manufacture and use of artificial consolidated core samples in China. Abu Dhabi, UAE: Society of Core Analysts, 2004.
14. X. Chen and Y. Zhang, "Method for making artificial core using dry cement as cementing agent," Advanced Materials Research, vol. 875-877, pp. 387-391, 2014.
15. LiquidPerm, Operating Manual and Maintenance Manual of LiquidPerm. France: Vinci Technologies, 2018.
16. A. Atallah, H. Alshmlh, and M. Abbas, "Applications of wireline formation testing (WFT) and downhole fluid analysis (DFA): Reviewing the importance of this technology in reservoir evaluation," Journal of the Pakistan Institute of Chemical Engineers, vol. 49, no. 2, pp. 59-73, 2021.
17. L.W. Lake, Enhanced Oil Recovery. Englewood Cliffs, New Jersey: Prentice Hall, 1989.