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# Application of SDS/LABS in Recovery Improvement from Fractured Models

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***Abstract*—**This work concerns on experimentally investigation of surfactant flooding in fractured porous media. In this study a series of water and surfactant injection processes were performed on micromodels initially saturated with a heavy crude oil. Eight fractured glass micromodels were used to illustrate effects of surfactant types and concentrations on oil recovery efficiency in presence of fractures with different properties i.e. fracture orientation, length and number of fractures. Two different surfactants with different concentrations were tested. The results showed that surfactant flooding would be more efficient by using SDS surfactant aqueous solution and also by locating injection well in a proper position respect to fracture properties. This study demonstrates different physical and chemical conditions that affect the efficiency of this method of enhanced oil recovery.

***Keywords*—**Displacement, Fractured five-spot systems, Heavy oil, Surfactant flooding.

## I. Introduction

FRACTURED reservoirs contain 20% of oil reserves in the world. However, they contain 60% of remained oil in place which is much more than conventional reservoirs [1]. [2]. This is due to rapid movement of fluid toward production well that causes low amount of produced fluid from matrices. In addition, heavy oil reservoirs contain 75% of initial oil in place in the world. Since thermal methods are impractical and costly in some areas, chemical methods have attracted high interest and attention [3].

One of the most simple and inexpensive EOR methods is dilute surfactant flooding. Decrease in capillary forces, that is the main reason of oil trapping, is the essential concept in this method of EOR. Surfactants are mainly organic materials that formed from a hydrophilic ionic head and a hydro-carbonic trail. Thus those can be dissolved in both water and organic solvents. Surfactants absorb on interface of liquids and decrease interfacial tension.

Surfactants, respect to the nature of their polar head, are classified into three groups: cationic, anionic and zwitterionic [4].

Akstinat surveyed different surfactants that were used in EOR [5]. Akstinat did the experiment in high salinity conditions. Barakat [6] investigated role of surfactants chemical structure on determination of the IFT. Imbibition capillary rate of surfactants and polymer were compared by Babadagli [7]. [7] found that adding surfactants increases the ultimate oil recovery and also obtained the same results on carbonate reservoirs. But, Babadagli did not analyze the effect of different characteristics of fractures on recovery efficiency.

In this work, two types of surfactants with different physical and solvent characteristics at different concentrations were flooded in ten fractured models with various fracture characteristics to survey the effects of surfactant type and fracture properties such as fracture length, orientation, continuity, distribution and density.

## II. Experimental

### *A. Model*

The micromodel setup is composed of a micromodel holder placed on a platform. It includes: a camera which is supplied with a video recording system, a precise pressure transducer and a pump that is used to control the flow rate of fluids through micromodel. Fig. 1 is a schematic diagram of the experimental setup [5].

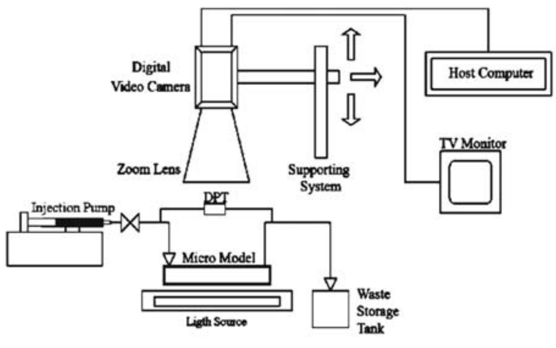


Fig. 1 Schematic diagram of experimental set up

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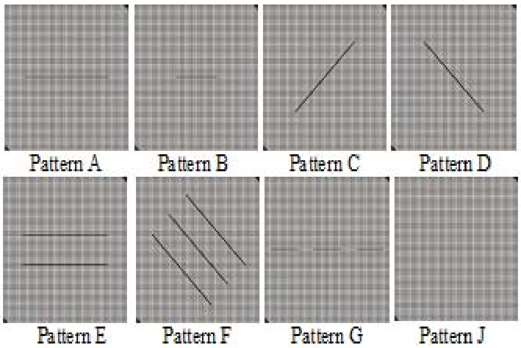


Fig. 2 Glass micromodels used as porous media

TABLE I
PHYSICAL AND HYDRAULIC PROPERTIES OF MICROMODELS

| Pattern | A | B | C | D | E | F | G | J |
|---|---|---|---|---|---|---|---|---|
| Length (mm) | 60 | 60 | 60 | 60 | 60 | 60 | 60 | 60 |
| Width (mm) | 60 | 60 | 60 | 60 | 60 | 60 | 60 | 60 |
| Average depth (mm) | 0.1 | 0.095 | 0.085 | 0.1 | 0.080 | 0.085 | 0.085 | 0.09 |
| Coordinate Number | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Pore Volume ($cm^3$) | 0.096 | 0.092 | 0.085 | 0.096 | 0.078 | 0.083 | 0.082 | 0.086 |
| Porosity | 52.29 | 52.2 | 52.47 | 52.47 | 52.29 | 52.29 | 52.48 | 50.08 |
| Permeability (mD) | 1800 | 1700 | 2000 | 1800 | 2100 | 2000 | 1900 | 1600 |
| Number of fractures | 1 | 1 | 1 | 1 | 3 | 3 | 2 | - |
| Fracture Orientation | 45 | 45 | 0 | 90 | 45 | 45 | 45 | - |

### B. Wettability

Because these models were in long time contact with toluene, they are completely oil-wet. This is due to toluene effect as an oily solvent to change wettability of glasses from water-wet to oil wet.

### C. Test Fluids

Surfactant solutions and oil are two fluids used in the experiments.

The oil used in this experiment is heavy oil which has API degree of 21 and viscosity of 68 cp at 20ºC.

Also, two types of surfactants were used for producing aqueous surfactant solutions: Sodium Dodecyl Sulfate (SDS) and Linear Alkyl Benzene Sulphonates (LABS) as anionic surfactants. SDS is dissolved in water but LABS is dissolved in n-Hexane. Since most tests were done by SDS, its IFT were found at different concentrations at 20 °C that is shown in Table II.

TABLE II
SDS/OIL IFT AT DIFFERENT SDS CONCENTRATIONS IN 22 °C

| Concentration (ppm) | IFT (dyne/cm) |
|---|---|
| 2000 | 0.065 |
| 1000 | 0.114 |

SDS surfactant solutions were used at concentrations of 2000 ppm, near its critical micelle concentration. In order to prepare surfactant solution, specific amount of surfactant powder is added to a specific amount of water in order to produce a solution with a specific weight fraction. It dissolves just by stirring. LABS surfactant dissolves in n-Hexane. The solutions which were used for these surfactant flooding tests are shown in Table III.

TABLE III
PROPERTIES OF SOLUTIONS

| Solvent | CMC (nM) | MW (g/mol) | Concentration (ppm) |
|---|---|---|---|
| Distilled Water | - | 18 | - |
| LABS | Undetermined | 326.49 | 2000 |
| SDS | 8.27 | 288.38 | 2000,1500,1000,500 |

### D. Experimental Procedure

Before each experiment, the micromodel is cleaned by toluene and methylene chloride and acetone and distilled water. Prepared micromodels are saturated by crude oil. All experiments were done in oil wet porous media and at ambient temperature and for horizontal displacement.

## II. RESULTS AND DISCUSSIONS

In this study, surfactant injection experiments were accomplished for various types of surfactants in various fractured models. Effects of each parameter on ultimate recovery was investigated and compared with the case of water injection.

### A. The Role of Presence/Absence of Fracture

Fig. 3 shows oil recovery after injection of 2 PV of SDS surfactant solution at concentration of 2000 ppm in fracture patterns: "D" with a fracture perpendicular to the flow direction, “C” with a fracture in line with flow direction and “J”, homogeneous pattern without any fracture.

As it is obvious, in pattern “C” due to presence of fracture in line with flow direction, breakthrough occurs sooner than in other patterns. But in pattern “D” with a fracture perpendicular to flow direction, fluid moves in fracture and breakthrough postpones. The ultimate recovery in this model is more than in others.

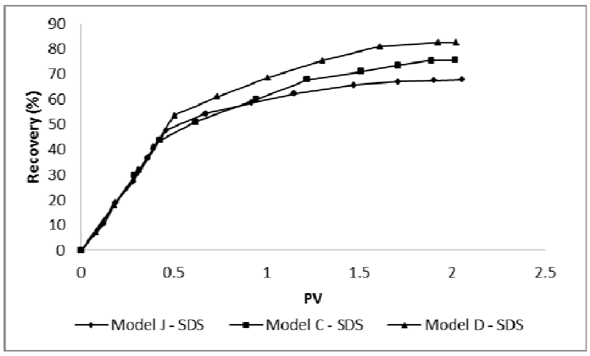


Fig. 3 flooding by SDS with the concentration of 2000 ppm in fractured and non-fractured patterns (patterns {C}, {D}, and {J})

### B. Effect of Surfactant Type

Fig. 4 shows recovery of pattern “C” due to the injection of distilled water, LABS and SDS surfactant solutions. It is clear that SDS surfactant solution causes more recovery than the other. This is due to the higher decrease of IFT by SDS. After

SDS, LABS has more effect on decreasing IFT and increasing oil recovery. The organic solution of LABS increases oil recovery in comparison with water but this increase is not as much as the increase of other surfactants. It is obvious that after breakthrough, recovery with SDS and LABS is significantly higher than with the distilled water. This shows better ability of surfactant solutions to improve fluid displacement from fracture to the matrix and decrease IFT between liquids in porous zone. From Fig. 4 it is obvious that using SDS that is dissolved in water as an aqueous solution result in higher oil recovery in comparison with LABS that is dissolved in n-hexane as an organic solution.

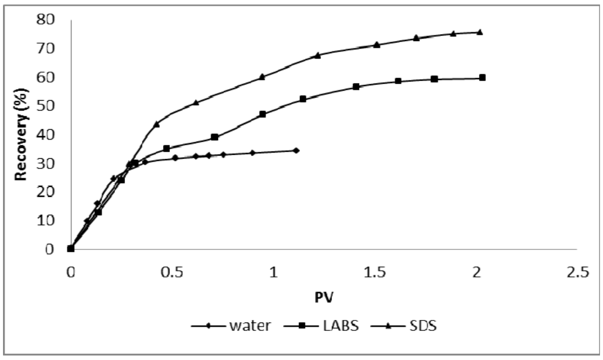


Fig. 4 Surfactant and water flooding with the concentration of 1200 ppm in constant flow rate 0.0008 ml/min in pattern {C}

### *C. Role of Fracture Length*

Fig. 5 shows oil recovery due to injection of SDS surfactant in patterns “A” and “B”. In pattern “B” due to the shorter length of fracture, injected fluids sweeps fracture and reaches to output immediately. But in pattern “A” due to longer length of fracture, it takes fluids more time to sweep fracture, but fluids transfer from fracture to matrix occurs better and more efficiently than in pattern "B"; so in pattern "A" breakthrough occurs later than in "B" and oil recovery after breakthrough is higher.

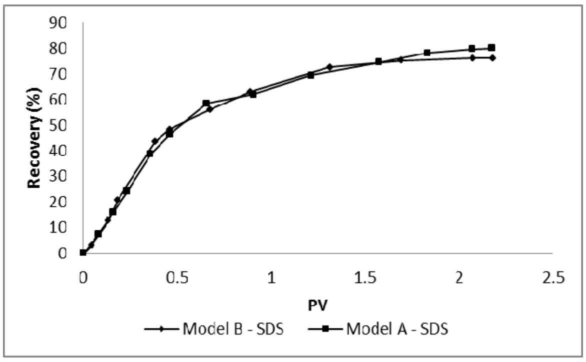


Fig. 5 Surfactant flooding by SDS with the concentration of 1200 ppm in constant flow rate 0.0008 ml/min for two different fracture lengths (patterns {A} and {B})

### *D. Role of Fracture Orientation*

Fig. 6 shows the results of injecting SDS surfactant solution at the constant concentration of 2000 ppm in patterns “A”, “C” and “D”. Clearly, breakthrough time and recovery in C is less than in D and in A due to presence of fracture along the flow path. In pattern C, initially, injected fluids flow through fracture. This results in low oil recovery at the breakthrough time, but after the breakthrough, fluids flow in the matrix and sweep a vast area of the porous zone. But in pattern D, presence of a fracture perpendicular to the flow direction results in flowing and diffusion of the surfactant solutions in a large area of the porous media which finally leads to higher oil recovery and later breakthrough. However, in this case, increase in oil recovery after breakthrough is negligible because sweeping becomes approximately completed at breakthrough time.

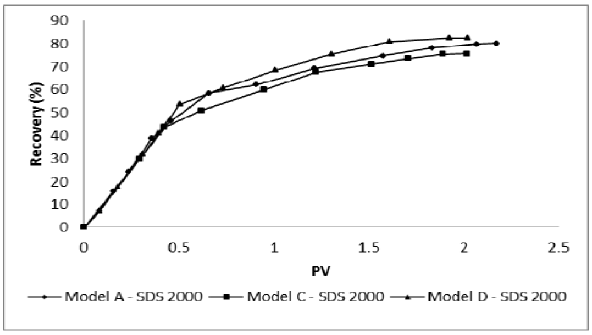


Fig. 6 SDS flooding with the concentration of 1200 ppm in constant flow-rate 0.0008 ml/min for different fracture orientation (patterns {A}, {C}, and {D})

### *E. Role of Fracture Density*

In order to investigate the effects of number of fractures, pattern D with one fracture perpendicular to the flow direction and pattern F with three fractures perpendicular to the flow direction were used. Also, patterns A and E, which have respectively one fracture and two fractures with the angle of 45 degrees to the flow direction, were used. Fig. 7 shows the results of injection of SDS and LABS surfactant solutions in patterns D and F.

It is obvious that in pattern “F” breakthrough time is more than in pattern D due to presence of more fractures perpendicular to flow direction. It is also clear that, oil recovery increases due to more fluid transferring from fracture to matrix that leads to a wider sweeping area in porous zone.

Fig. 8 also shows the effects of increase in number of fractures from patterns A with one fracture to pattern E with two fractures. As it is expected, both ultimate oil recovery and breakthrough time increase in the case of presence of more fractures. Although as it is expected, in pattern F, ultimate oil recovery and breakthrough time increase in the case of SDS surfactant more than in the case of LABS, this increase is not as much as in pattern D. It is due to presence of more fractures perpendicular to flow direction in pattern F that causes higher transition of injected fluid from fractures to matrix.

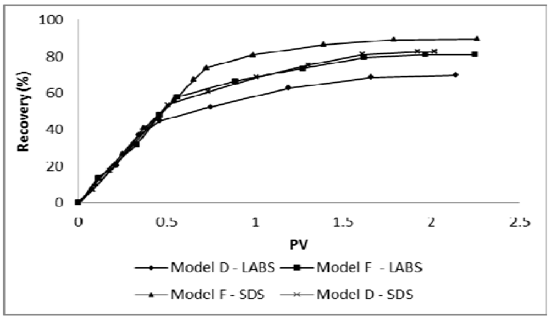


Fig. 7 Surfactant flooding by SDS and LABS with the concentration of 1200 ppm in constant flow rate 0.0008 ml/min for different numbers of fractures (patterns {D} and {F})

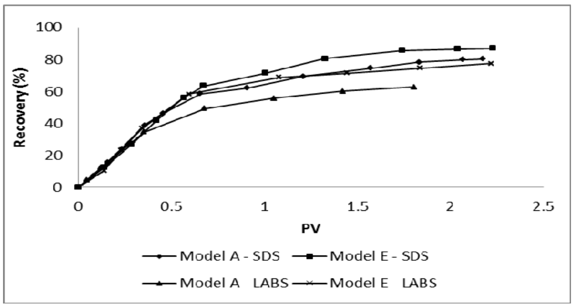


Fig. 8 Surfactant flooding by SDS and LABS with the concentration of 1200 ppm in constant flow rate 0.0008 ml/min for different numbers of fractures (patterns {A} and {E})

### *F. Role of Fracture Discontinuity*

To study the effect of fracture discontinuity, patterns A with one fracture and G with three fractures with equal total length of fractures are used, i.e. total lengths of those three fractures of pattern G is equal to the length of fracture of pattern A. SDS surfactant solution at concentration of 2000 ppm was injected into both models. As it is illustrated in Fig. 9, breakthrough time is approximately equal in both patterns; however, in pattern A, fluid transmission from fracture to matrix is occurred better due to its fracture continuity. In pattern G, since matrices exist between fractures, dispersion of fluid is not efficient.

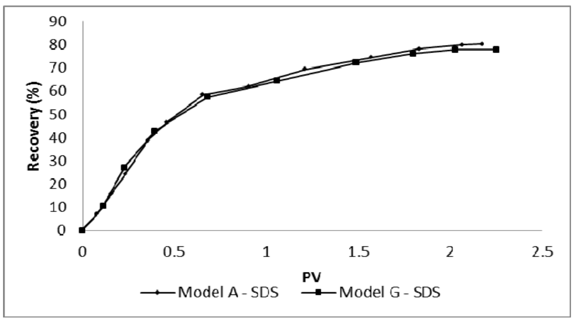


Fig. 9 Surfactant flooding by SDS with the concentration of 1200 ppm in constant flow rate 0.0008 ml/min in patterns {A} and {G}

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