Experimental Study on Polymer-Surfactant Effects on Enhance Oil Recovery from Dead-End

Hadi Jabari[1], Ahmad Ramazani S.A[2], Mohsen masihi[2]

[1]department of Petroleum Engineering, science and research branch, Islamic azad university, tehran, iran
[2]Department of Chemical and Petroleum Engineering, Sharif University of Technology, Tehran, Iran
Hadi_oilengineering@yahoo.com

Abstract: In this study, effects of polymer-surfactant flooding on oil recovery from dead end in glass micromodel have been experimentally investigated. A micromodel containing a long capillary connected to some dead ends having different aspect ratios have been designed and fabricated. Different polymer flooding and combination of polymer surfactant flooding experiments have been done at constant injection rate. Obtained results show that with increasing concentration of polymer in flooding fluid, the sweep efficiency from dead end increases considerably which could be attributed to the shear stress increase and also the hole-pressure increase in the dead ends. Presented results also show that increase in percentage of hydrolyzed and sulfonated groups in polyacrylamide chains results in more oil sweep efficiency from dead ends. The results show that addition of surfactant to polymer flooding solution increases oil sweep efficiency from dead ends considerably, which is much more significant for highly sulfonated polyacryamide polymers.

[Hadi Jabari1, Ahmad Ramazani S.A, Mohsen masihi. **Experimental Study on Polymer-Surfactant Effects on Enhance Oil Recovery from Dead-End**. Journal of American Science 2012;8(3):34-39]. (ISSN: 1545-1003). http://www.americanscience.org. 5

Key words: polymer- surfactant flooding, sulfonate, hydrolyze, dead end, Hole-pressure effect, elasticity attribute

1. Introduction

The petroleum industry recognized the problem of inefficient oil recovery by the conventional (primary and secondary) recovery methods in the early 1900. After that, extensive researches have been conducted to improve the displacement and sweep efficiency of oil recovery processes. Many different processes including water, surfactant and polymer flooding have been designed to improve the displacement efficiency by reducing the residual oil saturation in the reservoir. Surfactants are important chemical compounds widely used in industries. Most surfactants are chemical and synthetic. Surfactants are amphipathic molecules which enter the surface between two phases (with opposite polarities) to reduce surface tension through partial dissolution of hydrocarbons in water or dissolution of water in hydrocarbons. Surfactants are absorbed by surfaces or congregate at free surface of fluids or at interface of two different fluids. Surfactants are used to increase sweep efficiency. On the other hand, polymer flooding was designed in a manner to modify mobility ratio and sweeping efficiency. Polymer-surfactant flooding technologies are used to increase efficiency in terms of volume and displacement.

Detling1 (1994) used water-soluble polymers to develop polymer flooding process. In the following two decades, over 25 patents were registered in the area of polymer flooding. For the first time, Sandiford2 and Pye3 (1964) found that adding a small amount of water soluble polymer decreased water mobility in water flooding4. Injection of polymers to Bairon Field in December 1982, using polyacrylamide solution in 36 wells was another successful project5. Pope et al. (1979) analyzed sensitivity of micelle/polymer flooding. They developed Pope-Nelson6 simulator to add other effects and calculated oil displacement efficiency as a function of mass size, size of stimulating polymer, surfactants, oil concentration in slug, slag-to-oil mobility ratio, stimulator-slug ratio, and other factors7. In the Gulfex Field, Norway, Maldal et al. (1998) conducted polymer-surfactant flooding8. Dakhlia (1995) simulated polymer and surfactant flooding using horizontal wells. He argued that horizontal wells are potentially more capable for injection and production in polymer flooding compared to vertical wells and can improve sweeping efficiency9. White et al. (2002) used ASP to assess EOR in Illinois reserves which were water injected for a period of time. They found that decreasing capillary forces could improve EOR10.

Most of residual oil is difficult to displace and recover during water flooding process. Polymer and surfactant flooding are two important and high efficiency chemical flooding processes. However, it seems that combination of these processes can have synergistic effects and so efficiency of both processes can be increased with combination of these two processes. Application of simultaneous polymer and surfactant flooding can improve microscopic and macroscopic sweep efficiency. Since, a large percent of reservoirs rocks is consisted of the dead ends in which oil remains immobile during water flooding, study of sweep efficiency from dead ends is important to improve oil recovery efficiency.

Typically, there are four forms of the residual oil in the reservoir, the oil droplet, the oil film, the oil in throats and the oil trapped in the dead ends.. Although residual oil trapped in the dead-ends of pores media has not been still addressed enough in literature, it seems that a considerable part of residual oil remains in dead-ends and so for increasing EOR method efficiency sweep of this important part of residual oil should be considered too.

An important factor in improving macroscopic efficiency is uniform distribution of injected fluids over the whole reserve. The water flooding is one of the Enhanced Oil Recovery processes. However, this process has some drawbacks. One of them is the fingering problem in which water goes through the oil instead of pushing it. Under this effect, water enters a path with smaller pressure drop and makes its way to wells and the production process, thereby increasing the amount of the water produced. The more is the amount of water in producing wells, the higher will be the expenses of separation and water disposal at wellhead facilities, the higher will be the amount of water required for injection, and the more will be production costs. The residual oil trapped in the dead ends within the porous media is the most part of residual oil in a reservoir. The water flooding cannot normally displace or recover the trapped oil in the dead ends but adding of surfactant and polymer to the flooding water can enhance oil sweeping from the open capillaries and dead ends due interfacial, viscous and elastic phenomena. With injection of polymeric fluids with viscosity much higher than that of water into a reservoir, the displacing fluid traverses parallel paths and prevents fingering. This, in turn, increases macroscopic efficiency for EOR One of the most important factors to extract the oil from the dead ends is the cohesive force between the oil molecules and the rock surfaces. The magnitude of such forces depends on the oil, surfactant and rock type. Two forces must be overcome so that oil can be displaced in the channels: intermolecular forces in oil molecules and cohesive forces between oil molecules and rock surfaces. When the intermolecular forces are overcome, different layers of oil will be separated and driven forward. However, a layer of oil will remain on the surface, unless cohesive forces are overcome as well. Since cohesive forces are much larger than intermolecular forces, therefore, it plays an important role in determining microscopic efficiency of sweeping oil, depending on whether the rocks are water wet or oil wet. If the cohesive force between the water and rock surfaces is more than that of between the oil and rock surfaces, then the water can sweep the oil from the capillaries more effectively. In such a case the capillary is water wet. If the capillary is oil wet then a layer of oil will remain on the surface and the sweep efficiency is low. When the surface is water wet, the solid surface tends to attract water and oil takes the form of clotted liquid under intermolecular forces. When shear stress, caused by fluid passing over the oil, exceeds intermolecular forces, the oil surface in the hole takes a convex shape. Oil cannot wet the solid surface, and when shear stress exceeds intermolecular forces, a part of oil exit the holes depending on such factors as velocity of displacing fluid, magnitude of intermolecular forces, and shear stress (τ) on oil-water interface.

If the solid surface is oilwet, the cohesive forces will be extremely strong and should be considered carefully. The existence of the cohesive force at oil-rock interface creates a layer of oil over the surface which requires large forces for detachment. The oil surface in the hole has a concave form. The extent of concavity and extractable oil largely depends on intermolecular forces, the shear stress, and the shape and the size of the hole. The larger is the shear stress, the more oil will leave the hole. The shear stress largely depends on viscoelasticity of the displacing fluid11.

To study effects of the polymer and the surfactant on the oil recovery efficiency from open capillary and dead-ends, a special glass micromodel will be designed and manufactured. Then, this micromodel will be used to visualize sweep efficiency of water, water surfactant and water polymer surfactant solutions from dead-ends connected to maim capillary. Effects of polymer characteristic and polymer surfactant concentration on the oil sweep efficiency will be studied too.

2. Material and Methods

Figure 1 shows the designed and fabricated model for this study. Holes which should be considered as simplified deadend have different dimensions. In this study the 0.5mm(length) x 2mm(wide) hole, the hole number3, was examined. Given the complexity of the closed paths in real scale, and for sake of simplicity, we modeled the path as an ideal simple path shown in Figure 1. All measurements in the figure are in millimeters. For making the effects of capillary forces on the flow negligible and for more detailed examination of the fluid motion, the canal was modeled in millimeter scale. The canal is 166 μ deep.

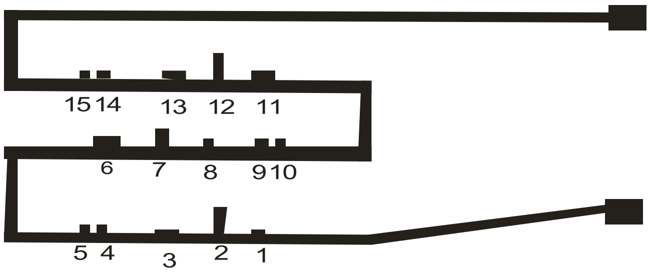


Fig1: An outline of constructed model saturated with oil and numbering of holes

Micromodel channel form has been designed by Corel Draw Software and laser beam has been used to engrave the drawing on the glass surface. Once the paths were engraved and cleaned, the glass has been stuck to another glass part by sintering them in a furnace. The spacing between the holes taken about 3 to 4 mm to provide enough length for the fluid to find fully developed flow between the holes.

For fluid injections, a very high accuracy pump fabricated by Quizix has been used.. The precision of this computer-controlled pump is 0.0001 cc/min. The pump is equipped with two cylinders placed in parallel with respect to each other and providing continuous injection.

A high pressures container is used to keep injected fluid. The fluid is poured into this container continuously during experiments. The pumped fluid pushes the piston and the piston drives the displacing fluid out of the cylinder into the model. Figure 2 provides a schematic of devices used under constant pressure.

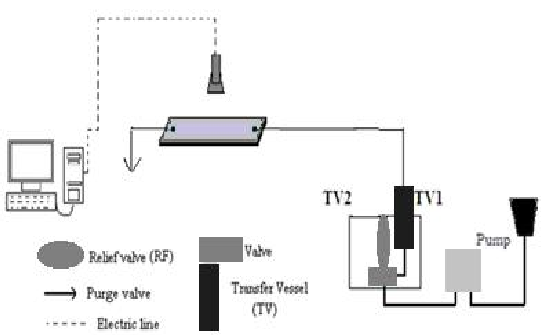


Fig2: Schematic presentation of designed system for experimental tests. systems at atmospheric pressure

Characteristics of different polymer solutions and solutions of polymers-surfactants which have been used for flooding experiments are presented in table 1. Characteristics of crude oil are given in table 2.

Table 1: Specifications of different solution samples used in flooding tests

Codes for polymer-surfactant samples	Concentrations (ppm)	Molecular weight of polymers (Million Dalton)	Sulfonation content (%)	Hydrolysis content (%)
PA	350	8	0	0
	700	8	0	0
	1400	8	0	0
PHPA	350	8	0	25
	700	8	0	25
	1400	8	0	25
AN105	350	6	5	0
	700	6	5	0
	1400	6	5	0
AN125	350	8	25	0
	700	8	25	0
	1400	8	25	0
SDS	2000	-	-	-
	1000	-	-	-
	500	-	-	-
PA+SDS	350+500	8	0	0
	700+500	8	0	0
	1400+500	8	0	0
	350+1000	8	0	0
	700+1000	8	0	0
	1400+1000	8	0	0
PHPA+SDS	350+500	8	0	25
	700+500	8	0	25
	1400+500	8	0	25
	350+1000	8	0	25
	700+1000	8	0	25
	1400+1000	8	0	25
AN105+SDS	350+500	6	5	0
	700+500	6	5	0
	1400+500	6	5	0
	350+1000	6	5	0
	700+1000	6	5	0
	1400+1000	6	5	0
AN125+SDS	350+500	8	25	0
	700+500	8	25	0
	1400+500	8	25	0
	350+1000	8	25	0
	700+1000	8	25	0
	1400+1000	8	25	0
H2O	-	-	-	-

Table2: specifications of used oil

Density	API	Type of fluid
0.8696	31.2	Oil

Model Wetability Investigation:

As seen in Figures 3 and 4, the oil surface inside the hole has a concave form. A layer of oil is formed on the wall of the micro-model. In addition, oil has also occupied the corners of the model. Considering the above fact. it can be concluded that the model should present oilwet behavior.

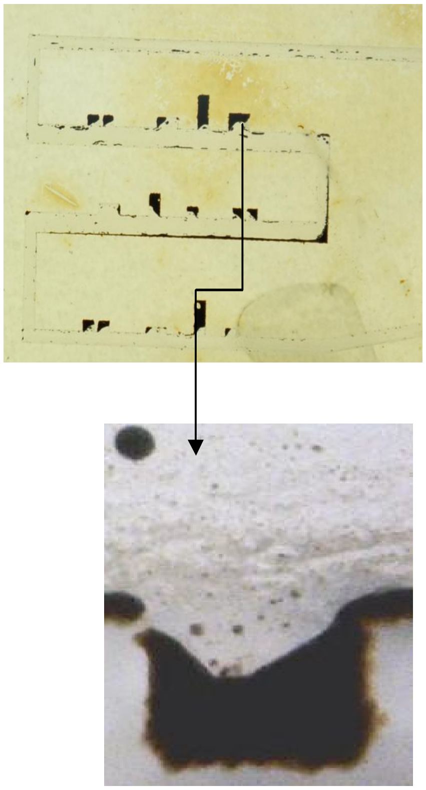


Fig. 3: Position of oil inside the holes

Fig. 4: Position of oil in walls and corners of micro-model

3.Results

Water and polymeric and polymeric-surfactant solutions given in table 1 are injected at constant rate (0.0001 cc/min) in the previously oil saturated micromodel. For complete saturation of micromodel with oil, appropriate vacuum has been employed. Experiments are started with investigation on effects of pure water and polymer solutions on recovery factor and continued with surfactant solutions and solutions containing both polymer and surfactants. These experiments could help us to investigate and compare effects of polymer types and polymer surfactant combination at constant and variable concentrations of them on oil sweep efficiency from dead-ends. Some of obtained results are presented. Some of obtained results are presented and compared through fig. 5 to fig9..

Comparisons of fresh water and some different polymer floodings on oil recovery from hole No. 4 are presented in figure 5.

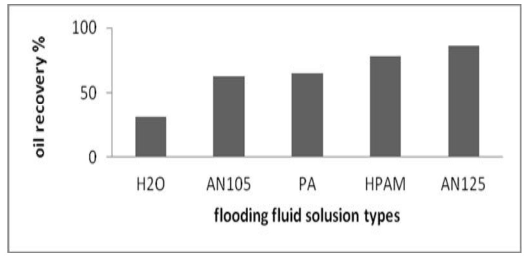


Fig. 5: Oil recovery percentage for water and different polymer solutions at concentration of 1400ppm in hole No. 3.

This figure shows that all polymer samples provide more efficiency in oil recovery from the considered dead-end comparing to fresh water. However, the most sweep efficiency (86%) is for sample AN125 who has 25% sulfonation content and the minimum efficiency among polymers are related to sample AN105 which has only 62.8% sulfonation content and with a molecular weight slightly less than that of AN125. This comparison show that sulfonation of polymer has remarkable effects on its ability for increasing oil sweep efficiency from the dead-end. Considering that all polymers are at same concentration (1400 ppm) and almost same molecular weight, it can be concluded that hydrolysis content could increase oil recovery but the increment is so much less than those of sulfonation content. Effect of surfactant concentration on oil recovery from the dead-end is presented in figure 6.

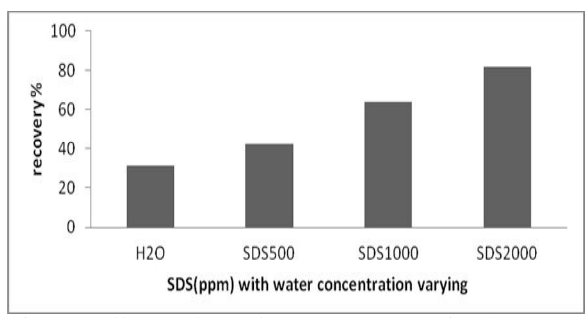


Fig. 6: Effects of surfactant concentration(ppm) on oil recovery from the dead-end.

This figure shows that with increasing surfactant concentration recovery factor increase noticeably, which is more significant at concentration of 2000 ppm of surfactant. This shows that this concentration should be close to critical concentration of surfactant where the interfacial tension reduces to it minimum value. However, comparison of presented results in figs. 5 and 6 shows that polymers especially high sulfonated one which can partially act as surfactant agent has much more effects on recovery factor than surfactant.

In fig. 7, effects of combination of polymer and surfactant on recovery factor has been presented. This figure shows that addition of 1000 ppm of SDS to polymer solutions results in significant increase in oil recovery from dead-end. This shows that addition of surfactant to polymer solution could have synergistic effects on oil recovery process especially for the highly sulfonated polymer samples.

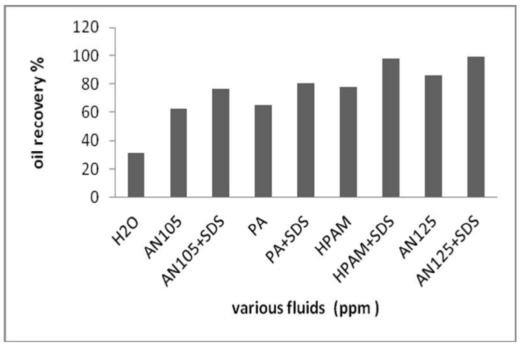
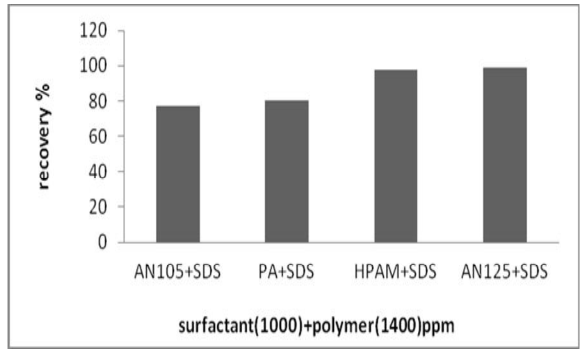


Fig 7: Effects of polymer types and combination of polymers and surfactant on oil recovery from hole No.3 (polymer surfactant concentrations are respectively and 1400pp and 1000 ppm)

Effects of polymer types on recovery factor for combination of polymer surfactant at constant concentration of polymer (1400 ppm) and surfactant (1000ppm) and at variable concentration of polymer and constant concentration of surfactant (500 ppm) have been represented, repectively in figs. 8. and 9., one can conclude that while combination of surfactant with hydrolyzed polyacrylamide only slightly increase oil recovery factor, combination of surfactant with highly sulfonated polymer dramatically increase oil recovery which can be observed almost for all combination of polymer surfactant. This shows that combination of hydrolyzed groups and surfactant does not show significant synergistic effects on oil recovery increment.

Effects of surfactant concentration on oil recovery by combination of polymer surfactant at constant concentration of polymers (1400ppm) have illustrated in fig 10. Considering presented results in this figure and presented results for oil recovery by pure polymer and surfactant, one can conclude that for almost all combination of polymers-surfactants oil recovery is more than recovery produced by each component alone. However, increase in recovery by combination of AN125 with surfactant at any concentration of the polymer- surfactant is so much more than those of each component alone. This phenomenon as previously mentioned should be due to high interaction between sulfonated groups of this polymer with surfactant groups which might produce associated polymer surfactant structure in flooding solution.



8: Effects of polymer types on oil recovery (%) at in hole No. 3.

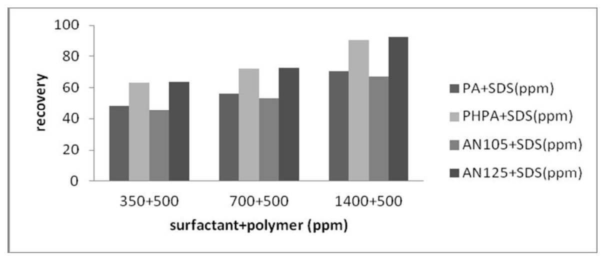


Fig. 9: Effects of polymer types and polymer concentrations on oil recovery by combination of polymer-surfactant in hole No3.

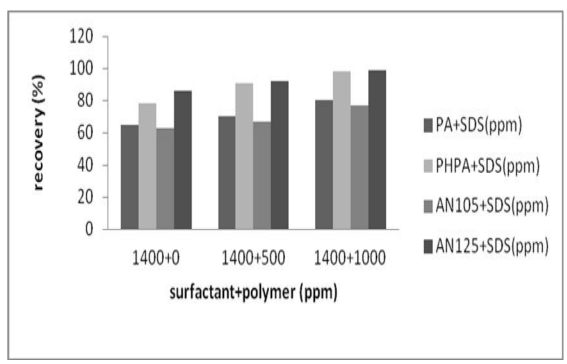


Fig. 10: Effects of surfactant concentration on oil recovery by combination of different polymers-surfactant in hole No. 3

4. Discussions

To investigated effects of polymer and surfactant concentrations and polymer characteristics on their abilities to recover oil from dead ends a glass micromodel having a long capillary connected to some deadends have been successfully used. Obtaining results show that increment in concentration of both polymers and surfactant increase oil recovery, but the increment is so significant for polymer samples containing high sulfonated groups. Presented results also show that oil recovery increment produced by combination of polymer-surfactant is higher than recovery increment produced by each component alone, which is also so much significant for highly sulfonated polymer samples. Analyzing of obtaining results, one could conclude that synergistic effects produced by combination of highly sulfonated polymer and surfactant should be attributed to associated structure produced between polymer chain and surfactant. This associated structure may increase viscosity more than polymer and reduction of interfacial tension more than surfactant.

Acknowledgements:

Authors are grateful to the Department of Journal of American Science.

Corresponding Author:

Ahmad Ramazani S.A., Ph.D., Polymer Engineering, Professor, Department of Chemical and Petroleum Engineering, Sharif University of Technology, Tehran, Iran. Ramazani@sharif.edu

References

1. C. Aurel, "Applied Enhanced Oil Recovery", Prentice Hall Publishing, USA (1995).
2. Sandiford B.B, " Laboratory and Field Studies of Water Floods Using Polymer Solutions to Increase Oil Recoveries", J. Pet, Tech. 917, Trans., AIME, 231 (Aug. 1964).
3. Pye D. J., " Improved Secondary Recovery by Control of Water Mobility", J. Pet. Tech. 911, Trans., AIME, 231 (Aug. 1964).
4. H.L. Chang, "Polymer Flooding Technology-Yesterday, Today, and Tomorrow", J. Pet. Tech., (1978).
5. Manrique and et al., "EOR Field Experiences in Carbonate Reservoirs in the United States", SPE 100063 (2006).
6. Pope G.A., and Nelson R.C., " A Chemical Flooding Compositional Simulator", SPE J. 339 (Oct. 1978).
7. Pope G.A., Wang B., Tsaur K., "A Sensitivity Study of Micellar/Polymer Flooding", SPE 357 (Dec. 1979).
8. Maldal T., Gilje E, Kritensen R, Kårstad T, Nordbotten A, Schilling B.E.R., and Vikane O., "Evaluation and Economical Feasibility of Polymer-Assisted Surfactant Flooding for the Gullfaks Field", Norway., SPE Reservoir Evaluation & Engineering, 161 (Apr. 1998).
9. Dakhlia H., "A Simulation Study of Polymer Flooding and Surfactant Flooding Using Horizontal Wells", Ph.D. Thesis, University of Texas at Austin, Austin. Texas. (1995).
10. Wyatt K., Pitts J., and Surkalo H., "Mature Waterfloods Renew Oil Production by Alkaline-Surfactant-Polymer Flooding", SPE78711 (2002)
11. B.C. Craft and M.F. Hawkins, "Applied Petroleum Reservoir Engineering", Prentice Hall Publishing (1991).

2/25/2012