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EVALUATION OF THE EFFECT OF ANIONIC POLYACRYLAMIDES ON STABILITY AND DISCHARGE OF FOAM INJECTION INTO OIL RESERVOIRS WITH DIFFERENT CHARACTERISTICS IN ENHANCED OIL RECOVERY

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Abstract

In this study the effect of anionic polyacrylamides on stability and discharge of foam injection into oil reservoirs with different characteristics in enhanced oil recovery was evaluated. As the Iranian reservoir formations are unique and few works has been done in this field, particular experiments must be carried out to enhance oil recovery. The efficiency of oil recovery with foam injection method, foams Stability with injection in porous media, effects of adding polymer to the foam formulation and the foam discharge was evaluated. The polymers used to increase the foam stability, were two types of anionic polyacrylamides, AN-105 with anionic degree (molar degree) of 5% and AN-125 with anionic degree of 25%. Two types of surfactants, SLES and NP30 were used. Two samples of F and S Brine water were used to prepare the foam. It was concluded that the polymer with higher molecular weight and anionic degree, had the best effect on foam stability. Also it was concluded that the salt sensitivity of foam would be decreased by increasing the amount of gas. Increasing the polymer concentration decreased the output rate of foam. AN125 increased the foam stability more than AN105 and as the salinity increased, the discharge rate increased.

Keywords: anionic polyacrylamides; surfactant; gas; foam stability; foam discharge; enhanced oil recovery.

1. Introduction

Foam agents are used in various applications in petroleum industries, including drilling, acid or hydraulic fracturing, gas production, blocking condense fluid flows and recovery processes. Surfactants are used to produce foam in low concentrations. Foams are used as mobility control agents in various processes such as secondary recovery and steam injection, CO_2 and nitrogen injection to improve performance. Surfactants and certain formulations are needed to produce foams to tolerate oil and electrolytes and can be stable at reservoirs pressure and temperature [1]. Foams have more effective viscosity than gas; therefore, they are used as a method to improve the sweeping efficiency of gaseous processes such as steam and CO_2 injection. Viscous fingering and gas overriding that caused by low viscosity and density of gas, can be reduced by means of foams. In a heterogeneous formation, preferably fluids flow in layers with high permeability and foam creates there and local resistance to flow increases strongly, thus the injected fluids are deviated to low permeable areas and process efficiency improves [2]. Also in water sweeping process, water moves from high permeable areas of the reservoir and reaches to the well, it reduces oil production and water sweeping will not be effective. Using foams is a useful method to reduce water production in water sweeping [3].

Gas mobility will decreases by injecting surfactants which can produce foam, which in turn reduces viscous fingering, gas overriding and transition to high permeable layers. The foam traps the gas, increases the gas saturation degree and decreases the oil saturation degree.

The foam can also affect the movement of fluid and reduce it. Gas in the foam is surrounded by a thin layer of fluid. Thin layer of foam creates cavities in the gas flow by contacting with the wall. A part of the gas could be held by immovable lamellas that block some of the flow paths. Correspondingly reducing the gas flow paths reduces the gas relative permeability. However, the actual viscosity of the gas remains unchanged and the gas shows an increase in apparent viscosity due to a decrease in the flow velocity [4]. The fluid behaves differently from the gas in presence of foam. Flow paths join together through the lamellas. During the foam growth, gas saturation degree increases and acts as an extra rock matrix by blocking the fluid flow. The relative flow permeability decreases by reducing flow paths. In other words, increase in gas saturation degree, affects the relative fluid permeability and decreases the fluid saturation degree [5].

ASP formulation has been used extensively in almost empty old reservoirs. Polymers are used in ASP process to reduce mobility. Polymers have some disadvantages:

1) High molecular weight polymers are large and may block rocks.
2) Polymers may be unstable at high temperatures and salinity.
3) High flow speed may damage the foam [2].

In a study by Srivastava [11], the polymer has replaced with gas to produce the foam. Core flooding was carried out successfully on sandstone and dolomite with low to moderate permeability using alkaline - surfactant - gas (ASG). By using negative salinity gradient, It has been able to mobilize the trapped surfactant and increase foam stability to improve the mobility ratio and to control the conformance during running forward [6-7]. Choosing an appropriate foam agent to reduce the mobility in gas flooding operations needs to sift many surfactants. Several methods for evaluating foams have been mentioned by researchers. Foams stability is measured commonly in three ways:

1) Determine the life time of bubbles.
2) Determine the foam volume at steady state (dynamic) under certain conditions of the gas flow, vibrating or cutting actions.
3) The vanishing rate of the foam column (static) [8].

Repeatability of the first method is difficult because of strong impact of small pollutions or vibrations. The other two methods are used however producing and disappearing the foam is not always monotonous. Dynamic method is the most appropriate one for measuring foams that disappear fast because of their short life time. Static foam tests are done for more stable foams. In a dynamic test, the foam is created with passing the gas flow through a porous inlet into the solution, if the inlet gas flow to the column remains constant, the foam volume will be constant and can be measured. These tests can be done by several methods such as standard ASTM tests [7]. These techniques are often used to determine the stability of foams that are gradually disappear. Other methods to determine the foam stability include displaying the physical properties of the foam. Several researchers used NMR spectroscopy and MRI imaging to investigate the foam stability [10].

In this study the effect of anionic polyacrylamides on stability and discharge of foam injected into oil reservoirs with different characteristics in enhanced oil recovery was evaluated. As the Iranian reservoir formations are unique and few works has been done in this field, particular experiments must be done to enhance oil recovery.

2. Experimental study

2.1 Materials and equipment

For foam stability tests, the polymers used to increase the foam stability, were two types of anionic polyacrylamides, AN-105 with anionic degree (molar degree) of 5% and molecular weight of 6 million (g/mol) and AN-125 with anionic degree of 25% and molecular weight of 8 million (g/mol). Two types of surfactants, SLES and NP30 were used. Two samples of F and S brine water were used to prepare the foam. Salinity degree of S brine water was more than F brine water. Water samples analysis and their salts and ions quantity, are given in tables 1 and 2, to prepare the synthetic samples.

Table 1 The compounds of synthetic F brine water and its salts and ions quantity in pH=4.9

Salt	Synthetic brine water (ppm)	Ion	Synthetic brine water (ppm)
NaCl	10.046	Na^+	3960
KCl	0.053	K^+	28
$MgCl_2$-$6H_2O$	1.219	Ca^{++}	790
$CaCl_2$-$2H_2o$	2.898	Mg^{++}	213
$MgSO_4$	0.333	Cl^-	7300
$NaHCO_3$	0.030	SO_4^{--}	266
TDS	12900	HCO_3^-	22

Table 2 The compounds of synthetic S brine water and its salts and ions quantity in pH= 5.1

Salt	Synthetic brine water (ppm)	Ion	Synthetic brine water (ppm)
NaCl	39.6889	Na^+	15730
KCl	0.4577	K^+	240
$CaCl_2$-$2H_2O$	6.4803	Ca^{2+}	2340
$MgCl_2$-$6H_2O$	2.7828	Mg^{2+}	400
$MgSO_4$	0.3333	Cl^-	29400
$NaHCO_3$	0.4295	SO_4^{2-}	290
TDS	50800	HCO_3^-	312

2.2 Test methods

2.2.1 Evaluation the efficiency of oil recovery with foam injection methods

In order to investigate the foam stability with simultaneous injection of gas and liquid method that is a type of foam injection processes to enhance oil recovery, an appropriate foaming device was set up. According to Figure 1, in this device, N_2 was led to the gas liquid mixing zone from a capsule by controlling the flow rate Brooks model. On the other hand, the cylinder containing surfactant and polymer liquid, led the liquid phase to the gas-liquid mixing zone by HPLC pump Waters-590 model. In simultaneous injection of gas-liquid, the foam with different volume fraction could be prepared. By changing the flow rate of two different phases that helped the evaluation of the foam quality. The height of the foam at the bottom of the scaled column of the device after a certain period of time, determined the optimum stability of the formulation. According to figure 2, a small cylinder filled with glass beads with average size of 600 microns in the outlet of the device, was used for homogenizing the gas-liquid mixture in these tests. If the homogenizing cylinder would not be used, non-uniform foam according to figure 3 was obtained.

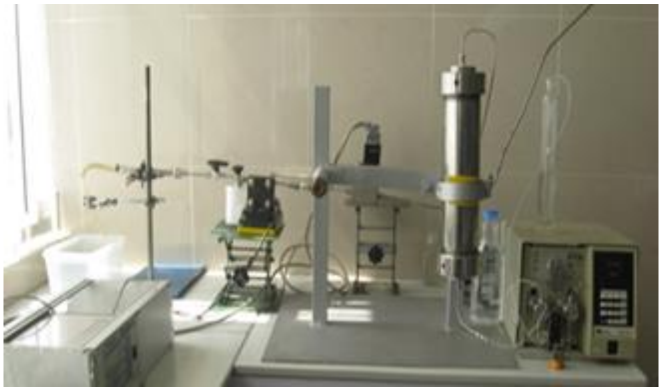


Figure 1 Foam preparation with specific quality system in surrounding pressure and temperature

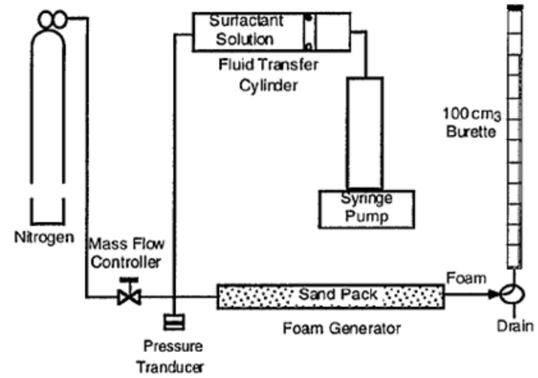


Fig. 2 Diagram of the specific foam preparation system with specific quality

Fig. 3 The obtaining foam before connecting homogenizing factor and homogenizing cylinder that is shown at the figure

2.2.2 Evaluation of foam stability with injection in porous media conditions

The stability of foams prepared with samples of the F and S brine water, the formulation of surfactants, type and different concentrations of polymers by different volume fraction with respect to the fluid and gas flow rate were examined. The prepared foams were stored in scaled cylinders. The foam stability and optimized foam formulation for injection in porous media were determined by comparing foam heights at the scaled cylinders in different periods of time. In this experiment according to figure 1, the gas was injected from one side and liquid containing brine water and optimized surfactant with formulation of 0.2% SLES + 0.3% NP30 was injected from the other side.

2.2.3 Effects of adding polymer to the foam formulation

AN105 and AN125 polyacrylamide polymers were mixed with different flow rates to increase the foam stability. The filling time of scaled cylinders with foams was 4 minutes. The foams stability was evaluated at 1, 5 and 30 minutes with determining the height of foams in scaled cylinders.

2.2.4 Evaluation the foam discharge

Evaluating the foam discharge was considered as continues step after evaluating the foam stability. Accordingly the sample was observed at different time periods with 1 (mm/min) of liquid flow rate and 7 (mm/min) of gas flow rate until rising to volume of 50 ml.

3. Results and discussion

The liquid discharge from the foam membrane caused thinning the membrane and gradually damaging the foam. If the factor which was caused the discharge rate of fluid through the membrane would be reduced, undoubtedly would affect the stability of the foam. Adding polymer to the solution increased its viscosity and reduced the liquid discharge from the membrane, which resulted increasing the foam stability. Using polymer increased the foam stability and the liquid viscosity, using the polymer with surfactant in oil recovery could have additional effect on improving the molecular movements. The polymer with higher molecular weight and anionic degree had the best effect on foam stability. As AN125 has higher molecular weight and more chain entanglements than AN105, it gave more stable foam as expected. Thus the calculations and results were based on AN125 properties. The test results were also in agreement with increasing foams stability. Figure 4 showed the effect of polymer type on foams stability in distilled water, F and S brine waters. As indicated AN125 had increased foams stability in F and S brine water. According to figures 5 and 6 it could be seen that the higher percent of polymer and higher amount of gas, increased foams stability in F brine water. Based on the results, foams stability for polymer concentrations of 0.075% and 0.1%

were nearly identical. So economically, using less percentage of polymer would be more appropriate.

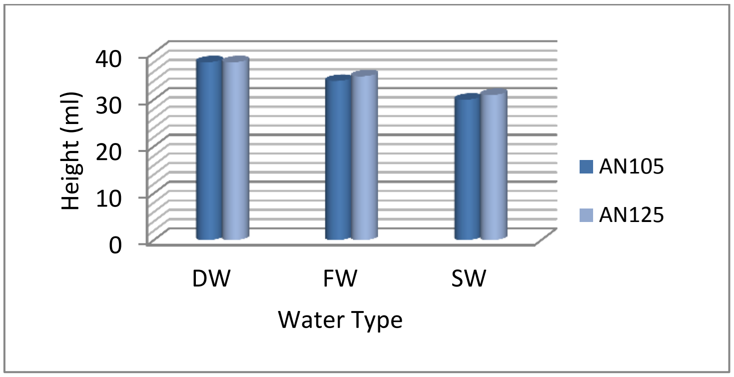


Figure 4 The effect of polymer type on foams stability in distilled water and F and S brine waters

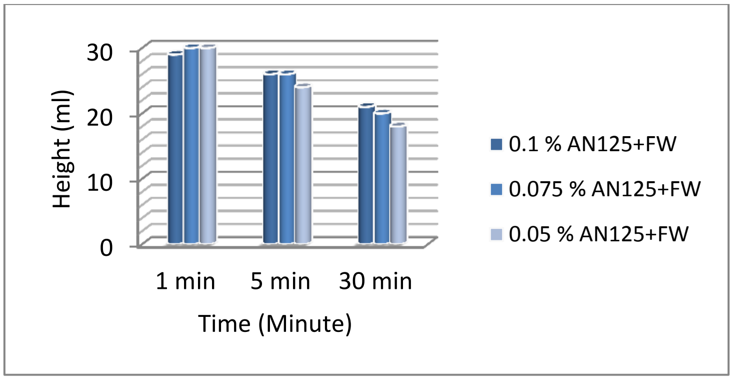


Figure 5 The height of foam after 1, 5 and 30 minutes, and different percent of polymer and injection rate of 1ml Liquid + 5 ml gas

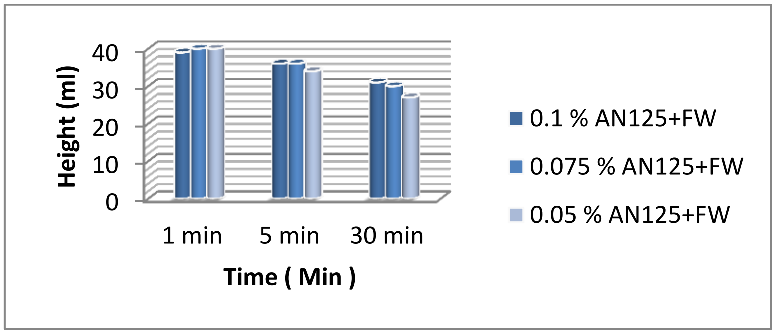


Figure 6 The height of foam after 1, 5 and 30 minutes, and different percent of polymer and injection rate of 1ml Liquid + 10 ml gas

It can be seen in figures 7 and 8, that the results were repeated. For S brine water that had more salinity, using 0.1% of AN125 polymer optimized foams stability and was more economical. The results of foam discharge can be seen in Figures 9 to 12. It was concluded that the salt sensitivity of foam would be less by increasing the amount of gas. This was because of the amount of liquid was less than gas in a certain foam volume. Also with increasing polymer concentration, the resulting foam was more stable because of increasing the foam solution viscosity. Increasing the polymer concentration decreased the output rate of foam because of increasing the viscosity and reducing the power of caring the gas. The optimum polymer concentration was 0.1% for stability. Increase in polymer concentration, decreased the salt sensitivity due to increasing the lamella film thickness. Also the rate of outlet foam reached to maximum with increasing the amount of gas and then decreased because of damaging the output foam. AN125 increased the foam stability more than AN105 and as the salinity increased, the discharge rate increased. The discharge rate decreased a little with increasing the polymer percent and then increased due to that the liquid phase got heavier and absorbing forces overcame the bonding forces because of increasing the viscosity.

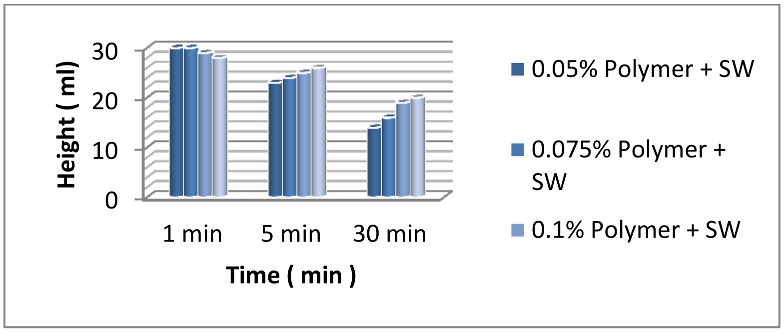


Figure 7 The height of foam after 1, 5 and 30 minutes, and different percent of polymer and injection rate of 1ml Liquid + 5 ml gas

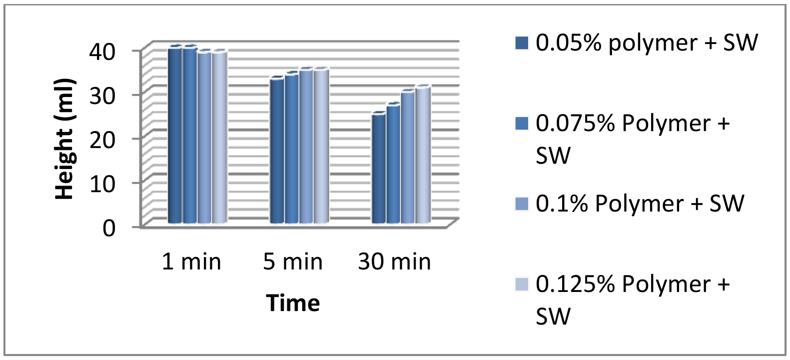
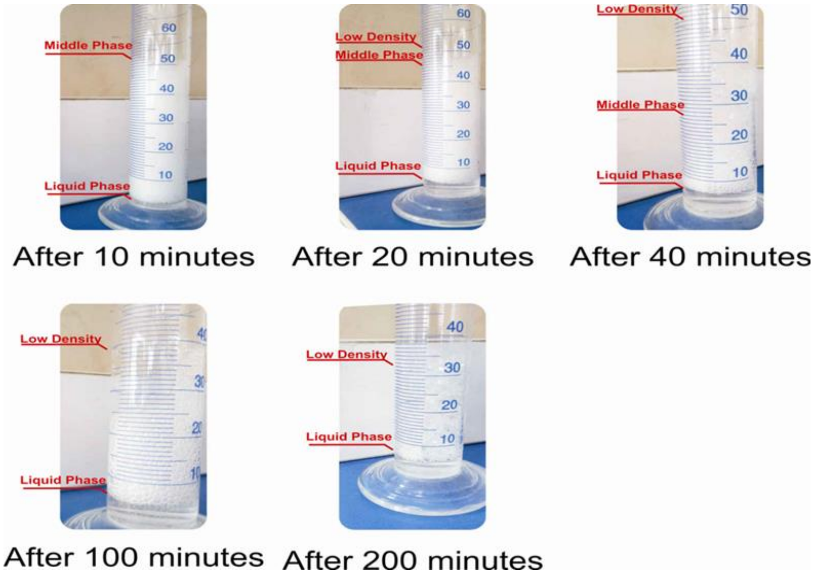


Figure 8: The height of foam after 1, 5 and 30 minutes, and different percent of polymer and injection rate of 1ml Liquid + 10 ml gas



After 10 minutes After 20 minutes After 40 minutes

After 100 minutes After 200 minutes

Figure 9 Sample discharge with formulation of 0.2% SLES + 0.3% NP30 in distilled water without polymer

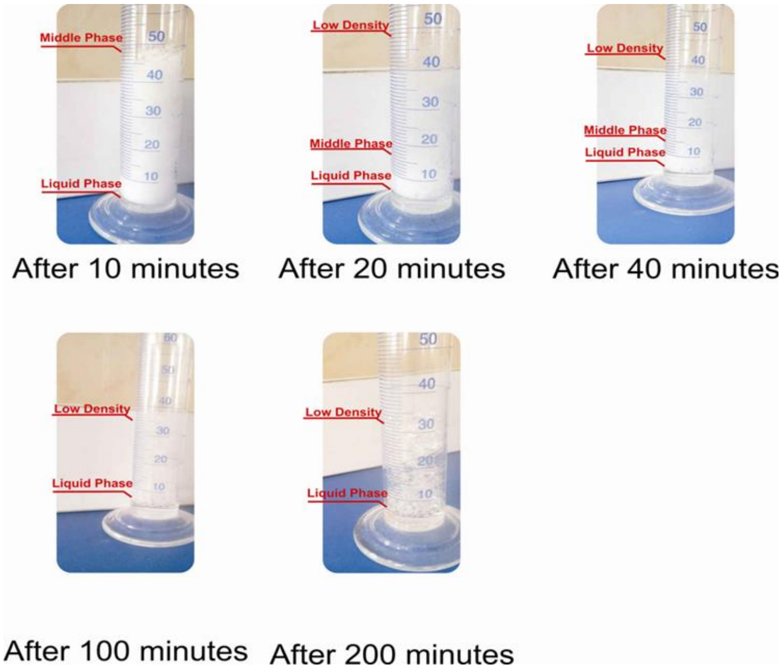


Figure 10 Sample discharge with formulation of 0.2% SLES + 0.3% NP30 in S brine water without polymer

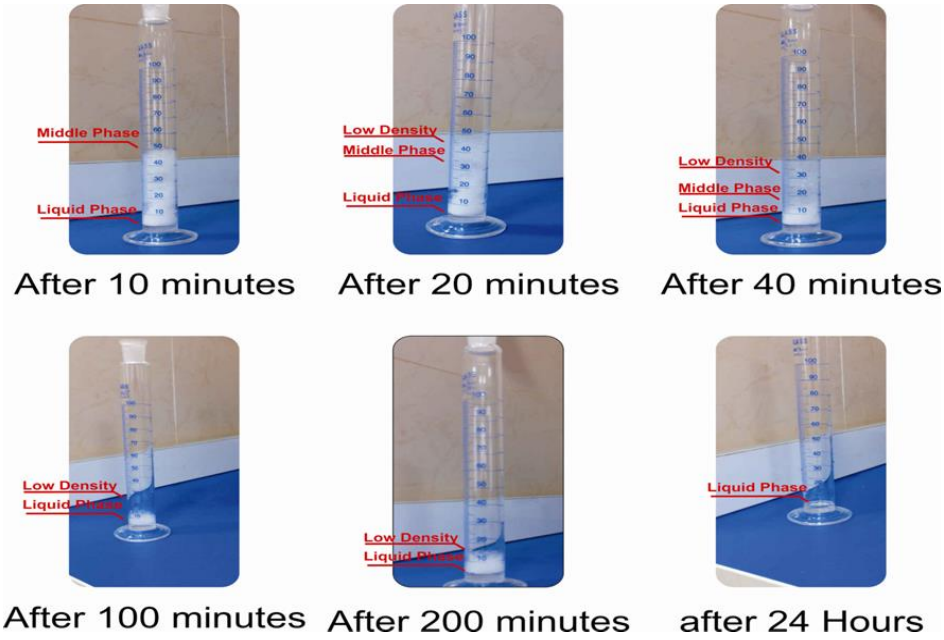
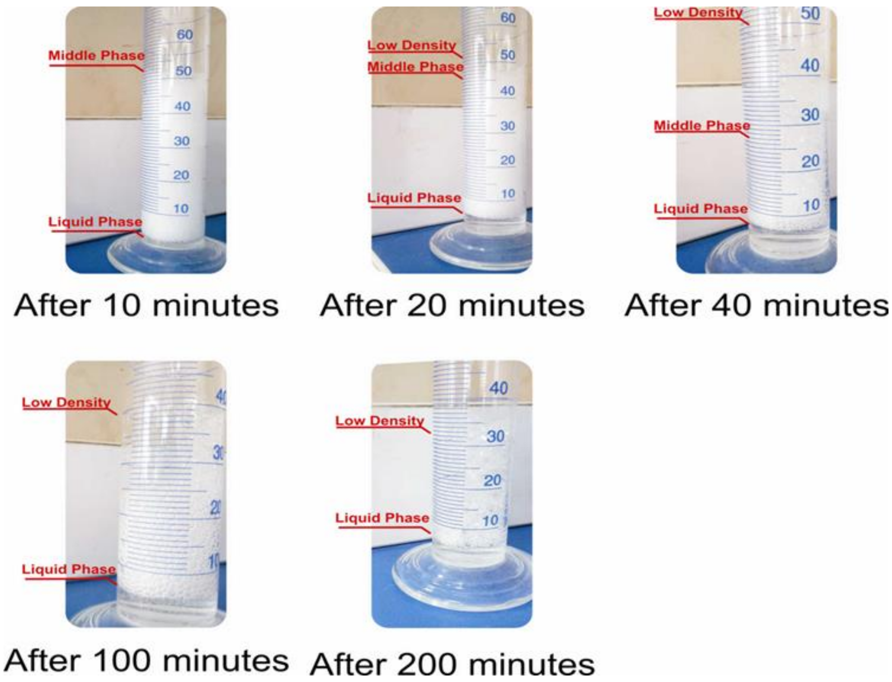


Figure 11 Sample discharge with formulation of AN125 0.2% SLES + 0.3% NP30 + 0.1% AN 125 Polymer in S brine water



After 10 minutes After 20 minutes After 40 minutes

After 100 minutes After 200 minutes

Figure 12 Sample discharge with formulation of 0.2% SLES + 0.3% NP30 + 0.1% AN 125 Polymer in distilled water

4. Conclusions

In this study the efficiency of oil recovery with foam injection, foams stability with injection in porous media conditions, effects of adding polymers to the foam formulation and the foam discharge was evaluated. It was concluded that the polymer with higher molecular weight and anionic degree, had the best effect on foam stability. AN125 had increased foams stability in F and S brine water. The higher percent of polymer and higher amount of gas, increased foams stability in F brine water. Foams stability for polymer concentrations of 0.075% and 0.1% were nearly identical. So economically, using less percentage of polymer would be more appropriate. For S brine water that had more salinity, using 0.1% of AN125 polymer optimized foams stability and was more economical. Also it was concluded that the salt sensitivity of foam would be less by increasing the amount of gas. The resulting foam was more stable with increasing polymer concentration. Increasing polymer concentration, decreased the outlet rate of foam. The optimum polymer concentration was 0.1% for stability. Increase in polymer concentration, decreased the salt sensitivity. AN125 increased the foam stability more than AN105 and as the salinity increased, the discharge rate increased.

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