

Laboratory investigation of the effects of parameters controlling polymer enhanced foam (PEF) stability

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ABSTRACT— *In the quest to achieve high stability foams, polymers can be used as the viscosifying agents of the aqueous surfactant solution of the external phase of foam, increasing foam apparent viscosity and thus improving foam stability. The alpha olefin sulfonate (AOS), sodium dodecyl sulfate (SDS), and sodium dodecyl benzene sulfonate (SDBS) surfactants were used as the foaming agent and relatively low to high (200-5000 ppm) partially hydrolyzed polyacrylamide (PHPA) polymer concentrations were added to solutions. All solutions were prepared in both fresh water and 4 wt. % NaCl and the effect of oil on PEF stability was investigated using paraffin and vaseline oil with different viscosities. Experimental results showed that, polymer addition to foam can be effective in improving foam stability as compared to conventional foam stability and even the addition of a small amount of polymer could enhance foam stability. Increasing polymer concentration from very low to high concentration increased foam stability, therefore the most stable foam was produced with the maximum polymer concentration in solutions. The preparation of solution with 4 wt. % NaCl had destabilization effect and reduced foam stability slightly as compared to solution with fresh water. Foam stability was substantially reduced when contacted oil in the solutions and the destabilization effect was more severe with paraffin oil rather than vaseline oil. Of all the three used surfactant, SDS was the most compatible with PHPA and produced the most stable foam, followed by AOS and finally SDBS surfactant.*

Keywords— PHPA, Surfactant, Foam, PEF, NaCl

1. INTRODUCTION

Gas breakthrough and poor sweep efficiency due to high mobility of injected gas are the most negative points of any gas flooding. Therefore, foam was proposed as the mobility control agent to reduce injected gas mobility in enhanced oil recovery (EOR) methods [1]. Foam is a dispersion of gas in a continuous liquid phase. The gas phase is made discontinuous by thin liquid phase called lamella from a continuous phase [2-4]. Although using foam as the mobility controller greatly enhanced the efficiency of EOR methods, one of the most important parameters in any foam flooding process is the foam stability. Increasing foam stability results in the better sweep efficiency and oil recovery as compared to less stable foam [5]. In EOR processes, polymers are known as the viscosifying agent to increase solution viscosity and reduce displacing fluid mobility. PHPA is water soluble polymer in which the repulsive forces between negatives charges of its chain provides a high viscosity in water. Solution viscosity can be increased significantly even by the addition of low concentrations of PHPA [6]. Polymer addition to foam solutions can improve the foam stability and enhance the foam performance by improving foam lamellae thickness and retarding the lamellae drainage rate. This process is called Polymer Enhanced Foam (PEF) in which polymer increases the lamella viscosity, therefore the produced foams are stronger and more stable than conventional foam [7]. Due to this feature, PHPA is one of the widely used polymers in EOR processes.

One of the earliest and most comprehensive researches was done by Sydansk [8,9]. He investigated the effects of variable polymer concentration and type, surfactant type and concentration, foam quality, gas type, absolute pressure, rheology and the effect of shear rate on PEF process. The results proved that, PEF was completely successful because produced foam was more stable than the conventional foam. Comparing the results of viscosity with and without polymer showed that PEF was more viscose than the conventional foam promising the mobility control fact by polymer addition.

Combination of polyacrylamide polymer and AOS surfactant with variable concentrations was successful in promoting solution viscosity and foam stability. Polyacrylamide polymer molecular weight (MW) has a positive effect on foam stability so that high MW polymers give more stable foam than low MW polymers.

Mei et al. [10] conducted a laboratory work to investigate the effects of factors affecting polymer enhanced foam stability made by partially hydrolyzed Polyacrylamide polymer and AOS surfactant. Results showed that optimum AOS concentration for producing foam was 1000 ppm, in other words, Critical Micelle Concentration value (CMC). Increasing polymer concentration influenced the foam stability greatly. The addition of even a small amount of polymer had a positive effect on foam stability and the highest polymer concentration produced the most stable foam, and the least stable foam was for the case of minimum polymer addition to the solution. Polymer molecular weight affected the foam stability in which high MW polymers improved the foam stability in higher degree as compared to low MW polymers.

Zhu et al. [11] used nitrogen and sandpack as the foam generator to investigate the effects of polymer type, concentration and MW; surfactant type and concentration; solution salinity on PEF performance. Results showed that foam characteristics were exceedingly improved by polymer addition and even a small amount of polymer increased the foam stability substantially. Hence, the higher polymer concentration and MW produced more stable foam as compared to partly concentration and low MW polymers. The presence of crude oil by a considerable amount had a negative effect on PEF performance and foam stability decreased when contacted with oil. When crude viscosity was low, the destabilization effect of crude oil on PEF stability was more critical than when crude viscosity was high. AOS surfactant was highly compatible with polymer addition, and the produced foam was reasonably stable in which the optimum surfactant concentration was near its CMC value and values higher than CMC concentration had no significant effect on foam stability.

Polymer addition to foam can enhance foam stability, however this improvement is a function of several parameters such as type of polymer, type of surfactant, compatibility of surfactant with polymer, the presence of brine, the presence of crude oil and viscosity of crude oil as well. The positive impact of polymer on foam stability has been reported in the literature, however the role of other parameters such as the effect of crude oil viscosity in conjunction with different surfactants are not well understood yet. Therefore, in this study we widen the scope of our research to investigate the effects of multiple parameters such as crude oil viscosity, surfactant type, the presence and absence of NaCl and their impact on foam stability.

2. EXPERIMENTAL PROCEDURE

2.1 Materials

The effects of polymer concentration on foam stability were investigated using PHPA polymer with variable concentrations of 200, 500, 700, 1000, 2000, 3000, and 5000 ppm. Three different surfactant types (SDS, AOS and SDBS) with relatively low and high concentrations of 200, 500, 1000, 2000, 3000, 4000, and 5000 ppm were used as the foaming agent. The effect of salt presence on foam stability was investigated through using 4 wt. % NaCl in the solutions and for all the solutions, foam was generated using gaseous CO₂. The effect of crude oil presence on PEF stability was investigated using paraffin oil (viscosity of 1.5 cp) as low viscosity oil and vaseline oil with the viscosity of 23 cp as high viscosity oil.

2.2 Foam stability apparatus

Foam stability apparatus was designed based on ASTM D892 [12], which is the standard test method for foaming characteristics of lubricating oils. The foaming test apparatus consists of a 1000 ml graduated cylinder (foam column), an HPLC pump, CO₂ tank, and a solution container. The graduated cylinder is fastened to a 25.4 mm (1 in.) in diameter spherical stone gas diffuser from the bottom. The gas diffuser is made by sintered five-micron porous stainless steel to generate bubbles. The cylinder is fitted with a stopper at the top with a hole in the center for CO₂ outlet. The CO₂ was supplied from a cylinder with an initial pressure of 68 bar. Figure 1 shows the schematic diagram of the foam stability apparatus.

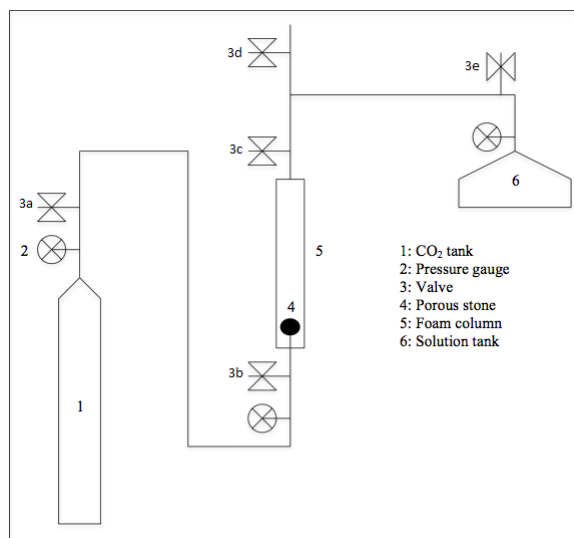


Figure 1: Schematic diagram of foam stability apparatus

2.3 Foam stability procedure

This method was based on the pressure adjustment in the cell. The gas pressure was set at two atmospheres (atm.) before entering the cell and was allowed to pass through the permeable stone by opening the valve 3a., enter the cell and generate foam in the cell. The CO₂ flowed upward through the porous stone and depending on the effectiveness of the surfactant for foam generation; the bubbles form a layer of foam. The gas injection was continued until the whole cell became full of foam before the injection valve was closed. Simultaneously time recording for measuring the foam stability was started. After the experiment was completed, solutions were taken out of the system. The cell was washed and prepared for the next test. In this study foam stability was defined as the time required for 80% of the liquid to drain from the foam column. It was measured from the time of halting gas injection until only 20% of the initial foam was remained in the cell column [13].

2.4 Solution preparation

Surfactant solutions were prepared in a standard 1000 ml volumetric flask. Surfactants were first weighed on mass basis and poured into the volumetric flask and then distilled water was added to complete the solution to the final weight (1 kg). After the preparation of the stock solution, it was diluted to obtain the desired concentrations of 200, 500, 1000, 2000, 3000, 4000, and 5000 ppm. Polyacrylamide was obtained as powder. Magnetically driven stirrer method was used to prepare the polymer solutions. Distilled water was poured into a beaker with a magnetic stir bar. Stirrer was turned on vigorously enough to generate a vortex, and then lightly sprinkled polymer powders directly into the vortex. The moment that polymer was added, the stirrer was slowed to avoid any mechanical degradation. Stirring was continued for several hours until a uniform solution was achieved. After giving the required time, stirring was halted and solutions were allowed to stand overnight. In the case of NaCl present, all the solutions were prepared by NaCl instead of distilled water. This procedure was repeated for different polymer concentrations. After preparation of all these solutions, then paraffin and vaseline oil was added to the solutions.

2.5 Surface tension measurement

The surface tension technique was applied to determine the CMC value for different surfactant solutions. A Krüss tensiometer (Krüss GmbH, Hamburg, Instrument Nr, K6) with a platinum-iridium ring was used to measure the surface tension. ASTM designation of D1331-98 was used to calibrate the tensiometer prior to any measurement. In this method, the required force to pull the platinum ring from the surface film is measured. For each solution, CMC reading was repeated three times to minimize the errors and then the average of these readings was recorded. All the calibration and surface tension measurements were conducted at constant room temperature of 25±1 °C. A plot of surface tension versus surfactant concentration was plotted for each surfactant and CMC value for each surfactant was simply defined as the point of lowest surface tension. The surface tension values after this point would be relatively constant with small changes.

3 RESULTS AND DISCUSSIONS

3.1 Surface tension measurement

Three different surfactants (AOS, SDS, and SDBS) were used as the foaming agent in this study. All surfactant solutions with variable concentrations (200-6000 ppm) were prepared in fresh water and then surface tension of each

solution was measured using Krüss tensiometer and results are presented in Table 1. Surfactant addition (even a small amount of 200 ppm) to fresh water decreased surface tension significantly and this reduction happened for all three surfactant, however results showed that SDBS was more efficient in reducing the surface tension followed by AOS and finally SDS.

Table 1: Surface tension measurement using Krüss tensiometer

Surfactant concentration (ppm)	SDS surface tension (mN/m)	AOS surface tension (mN/m)	SDBS surface tension (mN/m)
0	72	72	72
200	42.1	38.5	31.5
500	35.1	32.3	30.6
1000	32.6	31.8	28.4
2000	32.5	31.6	29.1
3000	33.1	31.5	28.7
4000	32.9	31.6	29.2
5000	32.4	31.5	28.1
6000	33.5	31.5	28.4

Critical micelle concentration (CMC) that refers to the concentration at which surfactant solutions begin to form micelles in large amount is one of the main parameters of each surfactant. Figure 2 is the plot of surface tension variation versus surfactant concentration. As it is shown, surface tension is reduced significantly up to concentration of 1000 ppm and after that the variation of surface tension is negligible. This means that, 1000-ppm concentration is the CMC of these three surfactants. Therefore, 1000-ppm SDS, AOS, and SDBS surfactant will be used as the foaming agent in all the experiments.

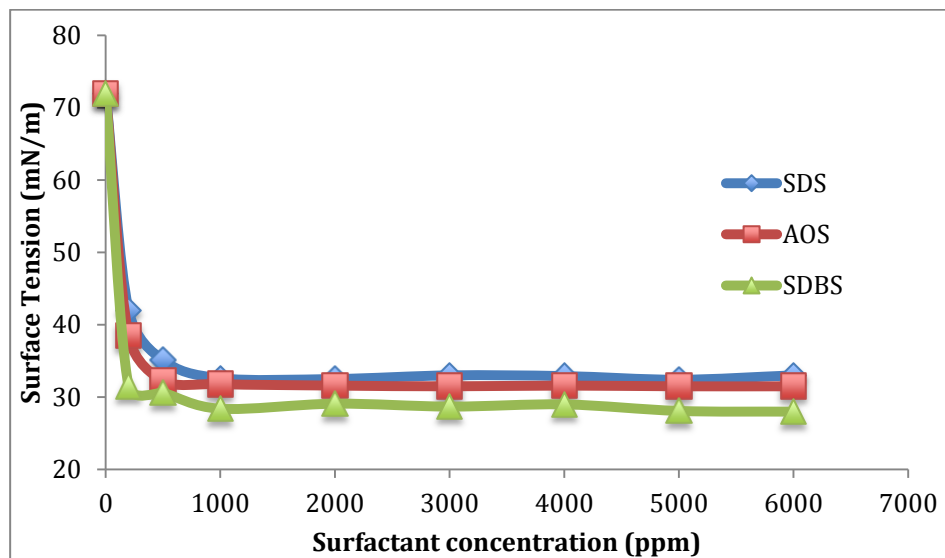


Figure 2: Variation of surface tension with surfactant concentration

The effect of polymer concentration on surface tension was investigated using variable concentration of PHPA and three different concentrations of 200, 1000, and 3000 ppm for each surfactant. Solutions were prepared and results are presented in Table 2. As results show, surface tension is in direct relationship with polymer concentration and increasing polymer concentration increases surface tension significantly. This negative effect is more severe with low surfactant concentration such as 200 ppm and high polymer concentration (5000 ppm), however increasing surfactant concentration to higher concentrations such as 3000 ppm minimizes this effect substantially. The main function of surfactant is to lower surface tension and facilitates the foam generation, however these properties are modified when ionic surfactants contact polymer and surface tension significantly increases [14]. Figure 3 shows the variations of surface tension with different polymer concentrations (200-5000 ppm) and 200, 1000, and 3000-ppm surfactants concentration.

Table 2: Effect of polyacrylamide polymer concentration on surface tension

Polymer concentration (ppm)	200 ppm SDS (mN/m)	1000 ppm SDS (mN/m)	3000 ppm SDS (mN/m)	200 ppm AOS (mN/m)	1000 ppm AOS (mN/m)	3000 ppm AOS (mN/m)	200 ppm SDBS (mN/m)	1000 ppm SDS (mN/m)	3000 ppm SDBS (mN/m)
200	44.1	33.8	33.5	43.3	32.1	32.3	43.2	31.6	31.2
500	45.6	35.1	35.3	46.3	33.9	34.1	47.6	33.5	32.3
700	47.2	35.9	36.7	49.6	34.2	34.6	51.3	34.2	33.6
1000	47.5	36.2	37.1	52.2	37.1	36.2	56.9	36.8	35.1
2000	59.2	43.9	44.5	61.6	39.4	39.4	60.2	34.1	36.6
3000	74.7	48.4	45.3	73.4	40.8	40.2	70.8	37.6	36.9
5000	81.6	54.2	52.9	78.9	47.6	44.3	76.3	40.2	39.7

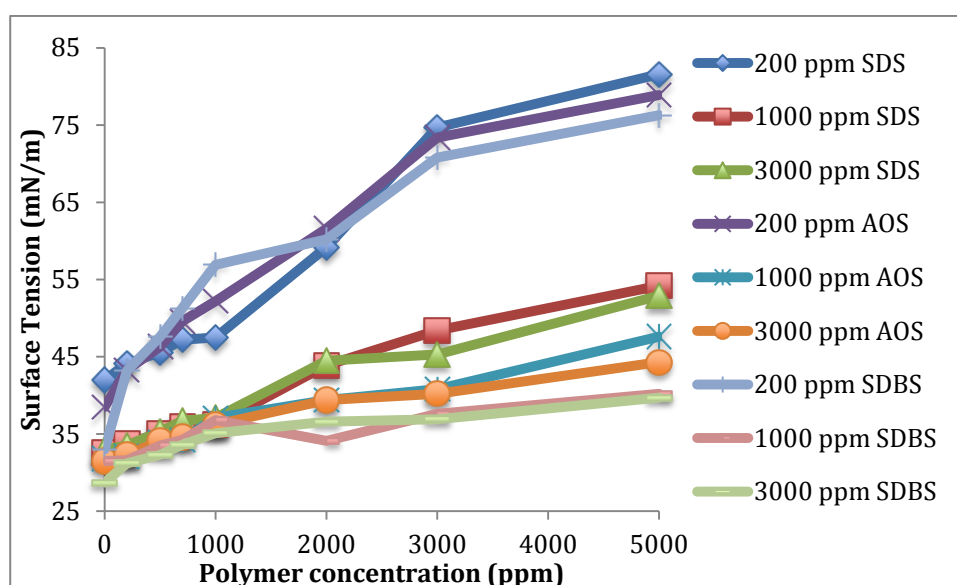


Figure 3: Effect of polymer concentration on surface tension

3.2 Conventional foam stability

Conventional foam is foam with no polymer in its structure. In order to emphasize the effect of polymer on foam stability, conventional foam was produced. Each solution was prepared in both fresh water and 4 wt. % NaCl with and without oil present. AOS, SDS, and SDBS surfactants were used as the foaming agent and time taken for 80% of the liquid to drain from column was measured for each solution. The results of conventional foam stability for the three surfactants are presented in Table 3. Conventional foam stability results showed that solutions made by fresh water as the aqueous medium are more stable than solutions made by 4 wt. % NaCl. Experiments conducted by oil presence in solutions showed that oil addition to the solutions had destabilization effect on foam and foam stability was reduced. Lamellas and plateau borders are more stable when fresh water is used in foam preparation but the addition of NaCl to solutions reduces the solution viscosity by screening the negative charges along the surfactants [6]. In general, all solutions made by fresh water (with and without oil) showed higher stability as compared to solutions made by 4 wt. % NaCl (with and without oil addition).

Of the three used surfactants, SDS produced the most stable foams in all solutions, followed by AOS and finally SDBS. Foam stability was affected by oil presence in the solutions and generated foams with vaseline oil were more stable than the foams with paraffin oil. Figure 4 shows the conventional foam stability results made by SDS, AOS and, SDBS surfactants in different solutions.

Table 3: Conventional foam stability with no polymer addition

Surfactant solution	Foam stability (min)					
	Fresh water	4 wt. % NaCl	Fresh water and paraffin oil	Fresh water and vaseline oil	4 wt. % NaCl and paraffin oil	4 wt. % NaCl and vaseline oil
1000 ppm SDS	76	57	41	54	28	39
1000 ppm AOS	59	43	34	41	23	30
1000 ppm SDBS	43	35	27	30	19	24

Foam consists of plateau boarder and lamella in which the liquid pressure is higher in the lamella than in the plateau boarder (due to the fact that gas-solid interface is curved). Therefore, as a result of liquid moving from the lamella into the plateau boarder, lamella thinning happens and finally it ruptures. The role of surfactant as a foaming agent is to reduce the surface tension of interface by placing at gas-solid interface rather than in the bulk [15]. Therefore the produced foam with the presence of surface-active materials such as surfactant is more stable than the generated foam with pure liquids such as pure water. Stability and destability of the plateau boarders is because of marangoni shear stress acting on the liquid at the interface that is due to surface-active gradient generation [16,17]. AOS, SDS, and SDBS surfactants were capable of reducing surface tension significantly; however the produced foams (conventional foam) were still unstable and ruptured rapidly as compared to polymer enhanced foams.

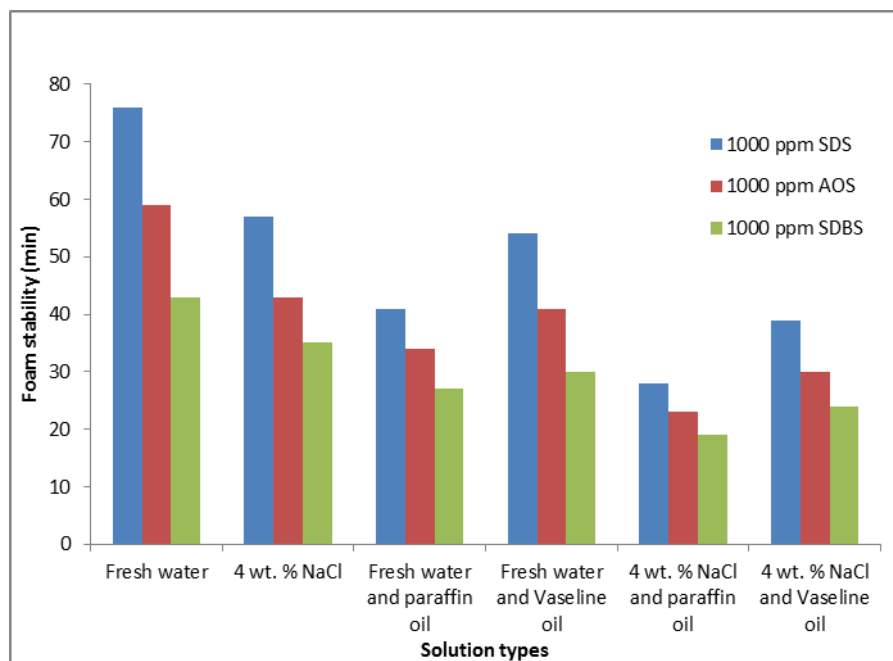


Figure 4: Conventional foam stability results

3.3 Polymer addition to foam solutions made by SDS surfactant

Relatively low to high polymer concentrations (200-5000 ppm) were prepared in both fresh water and 4 wt. % NaCl. Then paraffin oil and vaseline oil were added to the solutions separately and finally 1000 ppm SDS surfactant was added to each solution. After pouring the solutions into the cell, CO₂ was injected to the cell and foam was generated. After giving the required time to fulfill the whole set, injection was stopped and foam stability was measured for each solutions. Foam stability results are presented at Table 4.

In general, variable polymer concentrations were added to six different solutions including fresh water, 4 wt. % NaCl, fresh water and paraffin oil, fresh water and vaseline oil, 4 wt. % NaCl and paraffin oil and, 4 wt. % NaCl and vaseline oil. Comparing these results with conventional foam stability results show that foam stability has been increased significantly by polymer addition and even the minimum polymer concentration enhanced foam stability substantially. Polymer foam stability is in a direct relationship with polymer concentration and in all cases, the most stable foam was generated using the highest polymer concentration (5000 ppm) and the least stable foam was generated using the lowest polymer concentration (200 ppm). Results showed that, polyacrylamide is highly compatible with fresh water and polymer foam solutions made by fresh water were more stable than the solutions made by 4 wt. % NaCl. This relationship was also true even in the presence of paraffin and vaseline oil and solutions made by fresh water were more stable than the solutions with 4 wt. % NaCl, however the presence of oil significantly affected the stability results and foam stabilities were reduced. Vaseline oil with higher viscosity reduced foam stability less than paraffin oil with lower viscosity. Partially hydrolyzed polyacrylamide polymer is the most available and widely used of polymers for increasing solution viscosity and controlling the mobility [18]. The maximum chain extension is a result of repulsion between negative charges of high molecular weight polymer; therefore the addition of a small concentration of PHPA to water can increase solution viscosity significantly in the absence of electrolyte. However, in the presence of salt, negative charges along the polymer are screened and solution viscosity decreases [6]. Reduction in the solution viscosity with divalent salts can be as high as an order of magnitude compared with mono-valent salt, depending on the salt concentration and shear rate [19]. Two possible phenomena can be happened when oil is added to foam solution. Pseudoemulsion film is the phenomena that may happen when water is spread over the oil, therefore resulting in foam stability improvement by enhancing lamella and plateau boarder stability. The second phenomenon that we observed in our study is called unstable pseudoemulsion film in which water is not able to spread over the oil and make it wet. Therefore, oil water contact will be minimized by capillary forces, resulting in film rupturing and decrease in foam stability [20,21]. As a result, foam stability is significantly reduced when oil is added to foam solutions.

Figure 5 shows the polymer enhanced foam stability results made by SDS surfactant as the foaming agent with different solutions. As results show, the most stable foam was generated with different polymer concentration fresh water and the least stable foam was produced by 4 wt. % NaCl and paraffin oil.

Table 4: Foam stability solutions made by SDS surfactant

Polymer concentration (ppm)	Foam stability (min)					
	Fresh water	4 wt. % NaCl	Fresh water and paraffin oil	Fresh water and vaseline oil	4 wt. % NaCl and paraffin oil	4 wt. % NaCl and vaseline oil
200	91	74	43	59	29	40
500	99	80	60	74	36	46
700	108	91	73	90	41	52
1000	124	113	86	102	49	69
2000	212	179	119	139	60	81
3000	289	238	147	216	84	103
5000	417	364	195	299	102	137

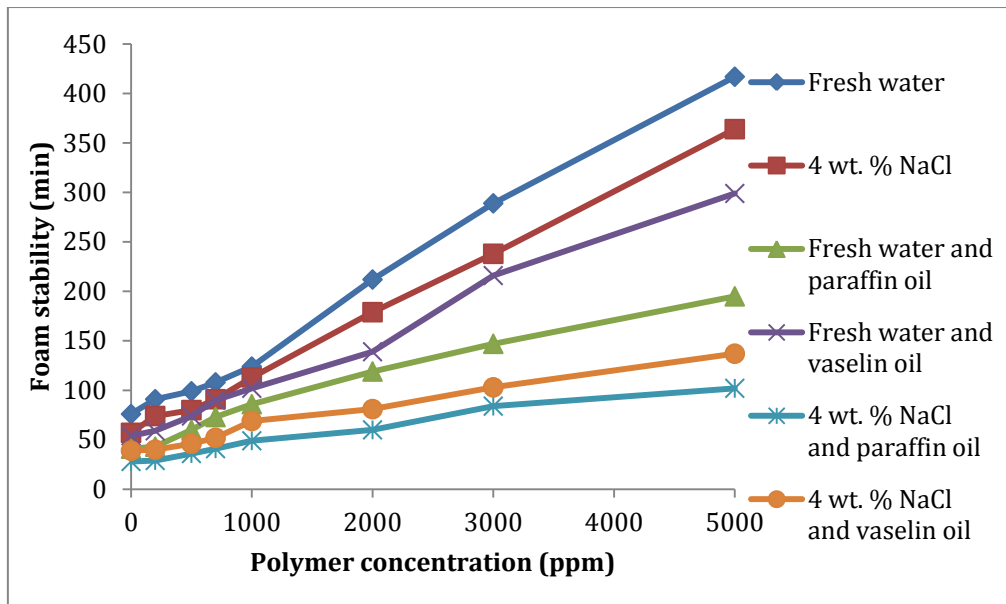


Figure 5: PEF stability results with SDS as the foaming agent

3.4 Polymer addition to foam solutions made by AOS surfactant

The second sets of experiments were conducted using AOS surfactant as the foaming agent. Variable polyacrylamide polymer concentrations were added to 1000 ppm surfactant in fresh water and 4 wt. % NaCl in the presence and absence of paraffin and vaseline oil. Foam stability of each solution was measured and results are presented at Table 5. As it was expected, polymer addition improved foam stability significantly so that increasing polymer concentration increased foam stability directly. The most stable foam resulted with maximum polymer concentration and the least stable foam produced with 200 ppm polymer. Foam stability was significantly compatible with solutions made by fresh water; however the addition of 4 wt. % NaCl reduced foam stability. For instance, in the presence of 5000 ppm polymer, foam stability was recorded to be 341 minutes for fresh water solutions and 217 minutes for solutions made by 4 wt. % NaCl. Foam stability reduced substantially with oil presence in the solutions in both fresh water solutions and 4 wt. % NaCl; however this impact was more obvious with paraffin oil rather than vaseline oil. For example, foam stability of solutions with 5000 ppm polyacrylamide polymer and paraffin oil in fresh water was measured as 131 minutes, 189 minutes for solutions in fresh water and vaseline oil, 75 minutes for 4 wt. % NaCl and paraffin oil and finally 93 minutes for 4 wt. % NaCl and vaseline oil.

Table 5: Foam stability solutions made by AOS surfactant

Polymer concentration (ppm)	Foam stability (min)					
	Fresh water	4 wt. % NaCl	Fresh water and paraffin oil	Fresh water and vaseline oil	4 wt. % NaCl and paraffin oil	4 wt. % NaCl and vaseline oil
200	67	48	36	44	24	31
500	80	56	39	49	25	33
700	95	70	45	56	31	38
1000	116	91	53	71	37	44
2000	189	138	71	93	44	59
3000	236	174	94	134	52	71
5000	341	217	131	189	75	93

Foam is a dispersion of gas phase in a continuous liquid phase and one of the main factors controlling foam stability is the thickness of liquid films called lamella. Thick lamella prevents foam structure from being drained and rupture. Therefore, decreasing liquid drainage rate by increasing solution viscosity can enhance foam stability significantly [22,23]. Decreasing drainage rate can be done by polymer absorption at the liquid-gas interface that increases the surface rheological properties. Besides, repulsive and attractive forces that are a function of the degree of absorbed polymer at the interface can control the drainage rate of foam irrespective of increases in the bulk viscosity [24,25]. However, the main mechanism responsible for reducing the drainage rate of foam at polymer enhanced foam solutions is the increase in bulk viscosity of solution. Therefore, the rate of fluid drainage out of plateau borders slows down and foam becomes more stable as compared to conventional foam [23]. Increasing polymer concentration increases solution viscosity and consequently foam stability is increased. The maximum polymer concentration improves foam stability as a higher degree as compared to minimum polymer concentration, however even the small addition of polymer to foam can increase foam stability significantly as compared to conventional foams of without polymer. When oil was added to foam solutions, oil contacted the gas water interface directly and foam was ruptured due to the movement of oil through lamellas and pinch off. The pinch off phenomena is accelerated when the bridging coefficient is positive and causing bubble coalescence by rupturing the gas-water-oil contact lines [26,27]. These phenomena results in foam stability reduction in the presence of crude oil.

Figure 6 shows the effect of polymer concentration on foam stability of solutions made by AOS surfactant with different solutions. As this figure shows, increasing polymer concentration from 200 to 5000 ppm increased foam stability in all solution types, however this enhancement was slightly reduced by the addition of 4 wt. % NaCl and oil.

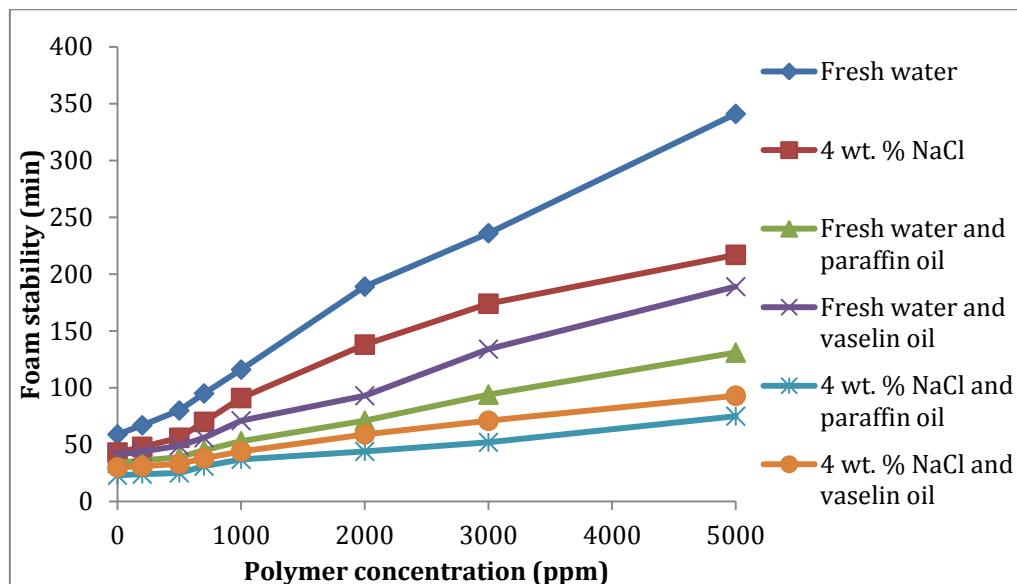


Figure 6: PEF stability results with AOS as the foaming agent

3.5 Polymer addition to foam solutions made by SDBS surfactant

The last set of experiments conducted using 1000 ppm SDBS surfactant to generate foam. Variable polymer concentrations were added to surfactant solutions made by fresh water and 4 wt. % NaCl in the presence and absence of paraffin and vaseline oil. Time taken for 80% of the liquid was measured for each solution and results are presented at Table 6. Experimental results showed that, solutions prepared in fresh water are the most stable foams and increasing polymer concentration from 200 to 5000 ppm increases foam stability significantly, however the minimum polymer concentration (200 ppm) still was effective in improving foam stability as compared to conventional foam. Addition of 4 wt. % NaCl slightly reduced foam stability as compared to solutions made by fresh water; however produced foams with variable polymer concentration were more stable than the conventional foam stability results. Paraffin and vaseline oil were also added to foam solutions in fresh water and results of these experiments showed that increasing polymer concentration to maximum concentration can increase foam stability substantially. At lower polymer concentration, increase in foam stability was not significant and this phenomenon got worst when solutions prepared in 4 wt. % NaCl instead of fresh water. When 4 wt. % NaCl was added to foams with variable polymer concentration and paraffin and vaseline oil, foam stability was substantially reduced as compared to solutions without oil present, however comparing

the results with conventional foam stability results showed that polymer addition to foam was successful even in the presence of paraffin and vaseline oil. In all solution tested, the destabilization effect of paraffin oil was more than vaseline oil.

Table 6: Foam stability solutions made by SDBS surfactant

Polymer concentration (ppm)	Foam stability (min)					
	Fresh water	4 wt. % NaCl	Fresh water and paraffin oil	Fresh water and vaseline oil	4 wt. % NaCl and paraffin oil	4 wt. % NaCl and vaseline oil
200	49	38	29	36	20	25
500	56	45	34	40	24	29
700	64	52	41	49	30	34
1000	81	69	53	62	36	48
2000	137	91	75	89	50	61
3000	174	128	96	120	64	86
5000	239	187	132	178	92	124

Comparing the result of polymer addition to foam solutions made by fresh water and 4 wt. % NaCl in the presence and absence of paraffin and vaseline oil shows that the most stability foam was produced with polymer addition to foam in fresh water and the least stable foam was generated with polymer addition to foam with 4 wt. % NaCl and paraffin oil. For example, foam stability of solution made by 5000 ppm polymer in fresh water was 239 minutes and this value was reduced to 92 and 124 minutes respectively when 5000 polymer was prepared in 4 wt. % NaCl and paraffin and vaseline oil respectively. Figure 7 shows changes of foam stability results with polymer concentration made in different solutions. It is believed that, there are several factors affecting foam stability in the presence of crude oil such as surfactant partitioning in the oil and depletion in the aqueous phase, production of a less favorable state for foaming because of surfactant adsorption by lamella, wettability alteration due to the absorption of oil component, displacing the foam stabilizing interface by oil spreading on foam lamella, oil emulsification that breaks and rupture the lamellas, bridging of foam films by oil droplets [27,28]. Polymer enhanced foam stability was affected significantly by the presence of oil in the system; in fact foam stability changed by oil viscosity. Less viscous oil (paraffin oil) reduced polymer enhanced foam stability more than high viscosity oil (vaseline oil), however the polymer additives improved performance of foams contacted by oils and enhanced foam stability [11].

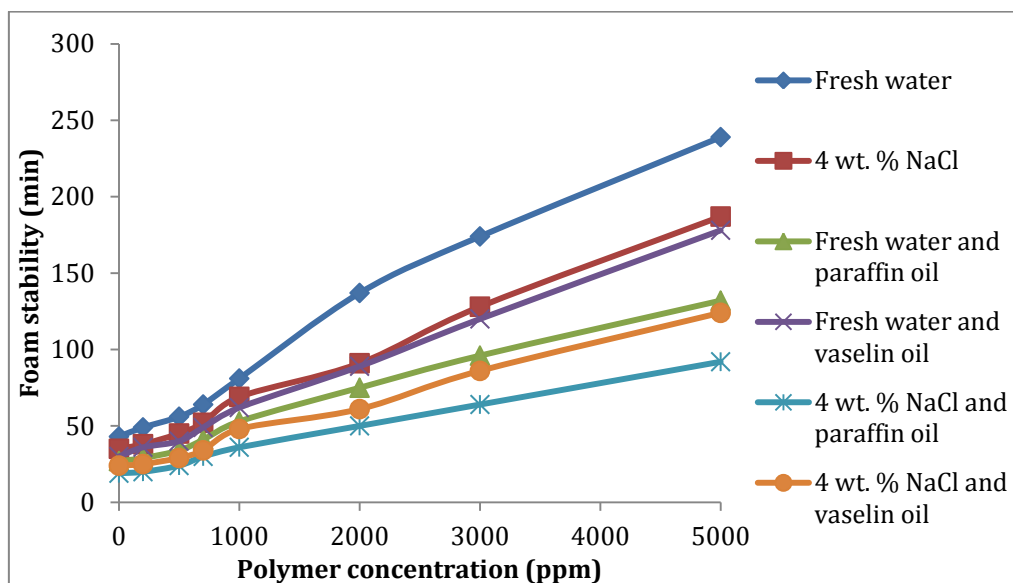


Figure 7: PEF stability results with SDBS as the foaming agent

4 CONCLUSION

Increasing solution viscosity by polymer addition to foam can decrease the liquid drainage time, therefore improving foam stability. Partially hydrolyzed polyacrylamide polymers with variable concentrations were used as the viscosifying agents of foams made by three different surfactant types, SDS, AOS and SDBS in the presence and absence of 4 wt. % NaCl. Paraffin and vaseline oil were added to solutions and foam stability in the presence of oil was measured as well. Time taken for 80% of the liquid was measured and results showed that polymer addition can improve foam stability significantly as compared to conventional foam. The most stable foam was produced when 5000 ppm PHPA was added to foam and the least stable foam was generated when the minimum polymer concentration (200 ppm) was added to foam. Foam solutions prepared in fresh water were more stable than the solutions made in 4 wt. % NaCl. Foam stability was significantly reduced when oil contacted foam in both cases of conventional and polymer enhanced foam, however the destabilization effect was severed with decreasing oil viscosity. All the three tested surfactants showed to be compatible with polymer addition; however SDS surfactant produced the most stable foam rather than AOS and SDBS surfactant.

5 ACKNOWLEDGEMENT

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