Laboratory Investigation of Static Bulk-Foam Tests in the Absence and Presence of Crude Oil

Evans Anto-Darkwah, Muhammed Rehan Hashmet, and Ali M. Alsumaiti

***Abstract*—Bulk foam-tests have been conducted at ambient conditions in the absence and presence of oil using Doumeen and Ethomeen surfactants and Nitrogen as the primary mixing gas. The effects of brine salinity and surfactant concentration on foam generation and stability are investigated. In another set of experiments, both brine salinity and surfactant concentration are fixed and the effect of type of mixing gas (N2, CO2 and air) on foam generation and stability are studied. Foam height after mixing with gas is recorded and it represents foam generation. The time for foam to break to half of its original height is recorded to represent foam stability. Comparison of results for experiments in absence/presence of oil reveals that oil is detrimental to foam generation and stability in this studies.**

***Index Terms*—Foam height, foam half-life, brine salinity, surfactant concentration.**

I. Introduction

The use of foams as mobility control agents in miscible and immiscible gas injection is an active area of research [1]-[3] and subject of many field tests [4]-[6]. Most of these research studies and field trials are to understand foam's mobility reduction ability related to solving viscous fingering and of much importance in the subsurface, the ability of foam to solve gas channeling in a heterogeneous reservoir. The successful implementation of a foam injection project depends mostly on the foamability/stability of the surfactant at the required reservoir conditions. Surfactant screening for foam projects is therefore of prime importance. There are two main surfactant screening methods: static bulk-foam tests at room temperature which requires simple equipments and procedures and dynamic foam tests at reservoir conditions which require special equipments and experimental design. In this study, our focus will be on static bulk-foam tests at ambient conditions to test the effects of surfactant concentration, salinity and gas type on foam generation and stability. Bulk foam tests serve as initial screening criteria where there are several surfactants to be tested [7] and additionally, bulk foam tests provides the opportunity of visual observations of foam performance. Static foam performance have been found not to have direct correlation with dynamic foam performance [8], [9]. Vikingstad *et al.* [10] contends that notwithstanding the possible differences between static and dynamic foam tests, static-foam tests may reveal important parameters in foam-oil interaction tests. All experiments are conducted in the absence and presence of oil to check the effect of oil on foam generation and stability.

II. Experimental Procedures

A. Materials Used

The surfactant used in all experiments is Doumeen (TTM) with a C16-C18 carbon chain length, a molecular weight of 240 g/gmol and was provided by Akzo Nobel. The brine composition consists of NaCl = 182.3g; $CaCl_2.3H_2O$ = 77.24g and $MgCl_2.6H_2O$= 25.62g. A typical light Middle Eastern crude oil is used in all experiments.

B. Procedures

The first series of experiments are conducted in the absence of oil. Different surfactant concentrations and brine salinity solutions were prepared from a surfactant stock solution of 5 wt% and brine stock of 275000 ppm by appropriate dilution with distilled water. The surfactants were stabilized with 5-7 drops of 10% HCl to move the pH to 7 (from cloudy to clarity). Total solutions of ten millimeters consisting of surfactant of different concentration and brine salinities are placed in a 50 ml graduated cylinder. The resulting solution was purged (mixed) with gas (Air, Nitrogen or Carbon dioxide) for 2 mins. The graduated cylinder was closed with a cork immediately after purging. The foam height above the liquid phase was recorded after gas purging stops. The height of the foam at time (t=0) represents the foam generation (foamability). The foam decay (breakage) was recorded as a function of time. The foam half-life is defined as the time taken for the original height of foam to break into half. The half-life is the stability characterization parameter for the foam.

The second series of experiments are conducted in the presence of oil using the same procedure and conditions outlined above. 2 ml of oil was added to the resulting 10 ml solutions of surfactant and brine and purged with gas for 2 mins. The foam height above the liquid phase was recorded and the rate of foam decay with time recorded.

III. Results and Discussions

A. Absence of Oil Experiments

Unless otherwise reported, the primary gas for mixing is Nitrogen for all reported results that follow. Table I shows the formulations used in all experimental runs.

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TABLE I: EXPERIMENTAL RUN FORMULATIONS

Parameters	**1A**	**1B**	**1C**	**1E**	**2B**	**2C**	**2E**	**3A**	**3C**
Brine salinity (ppm)	125000	205000	125000	165000	165000	165000	205000	108000	165000
Surfactant concentration (wt%)	0.5	0.5	1.5	0.29	1	1	1.5	1	1
Surfactant Vol (ml)	1	1	3	0.58	2	2	3	2	2
Brine Vol, ml	4.54	7.45	4.54	6	6	6	7.45	3.94	6
DI water (ml)	4.54	1.55	2.54	3.42	2	2	0	4.05	2
Total Vol(ml)	10	10	10	10	10	10	10	10	10

1) Effect of salinity

In these set of experiments, the surfactant concentrations were fixed at concentrations of 0.5, 1 and 1.5 wt % and the brine salinities were varied from 108000, 125000, 165000 and 205000 ppm. The foam height and half-life are recorded to evaluate the effect of salinity on foam generation and stability at room temperature conditions.

Table II shows the results for fixed surfactant concentrations of 0.5, 1 and 1.5 wt%. Brine salinity variation is between 100000-200000 ppm.

TABLE II: FIXED SURFACTANT CONCENTRATION EXPERIMENTS

Surfactant Conc (wt%)	Brine Salinity (ppm)	Height (cm)	Half-life (mins)	Experiment
0.5	125000	10	87.5	1A
	205000	6	229.5	1B
1	108000	19	162	3A
	165000	12	184	2B
	165000	9	162	2C
	165000	15	162	3C
1.5	125000	35	152	2E
	205000	6	225	1C

Fig. 1 shows the results for the effect of salinity variation on foam height and Fig. 2 also shows the results for salinity variation on foam stability at a fixed surfactant concentration of 0.5wt%. The results correspond to experimental runs 1A and 1B.

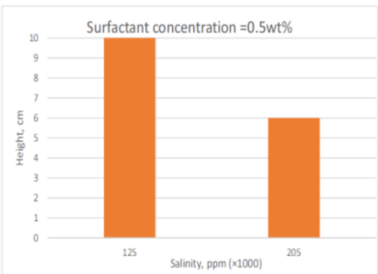

Fig. 1. Effect of Salinity on foam height.

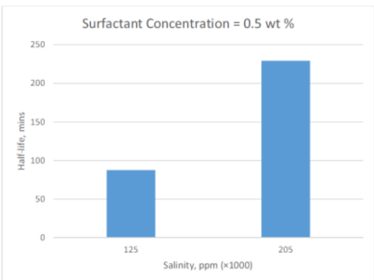

Fig. 2. Effect of Salinity on foam stability.

Results obtained at a fixed concentration of 0.5wt% (Runs 1A and 1B) shows that lower salinity promotes foam generation (see Fig. 1). The height for the low salinity brine (125000ppm) was recorded as 10cm at t=0 and that of the higher salinity brine (205000ppm) is 6cm. However, the stability time for foam is better for the higher salinity brine. This is to say that, the lower salinity foam breaks much quicker than the higher salinity foam. The same trend was observed in experiments using a fixed concentration of 1.5 wt% (Runs 2E and 1C) as shown in Table II. The trend of low salinity promoting foam generation was also observed for 1wt% surfactant concentration experiments. However, the stability time for low and high concentrations of brine are almost similar for Runs 3A, 2C and 3C (Refer to Table II).

2) Effect of surfactant concentration

The set of experiments under this section were performed such that the brine salinities were fixed at 125000ppm, 165000ppm and 205000ppm whilst varying the surfactant concentrations at 0.29, 0.5,1 and 1.5 wt%. The various experimental runs are shown in Table III.

TABLE III: FIXED BRINE SALINITY EXPERIMENTS

Brine Salinity (ppm)	Surfactant concentration (wt%)	Height (cm)	Half-life (mins)	Experimen t
125000	0.5	10	87.5	1A
	1.5	35	152	1C
165000	0.29	5	32	1E
	1	19	173	3A
205000	0.5	6	229.3	1B
	1.5	6	225	2E

Fig. 3 and Fig. 4 presents the foam height and stability variation with surfactant concentration at a fixed salinity of 125000ppm.

Higher surfactant concentration promotes foam generation and stabilizes foam as seen from Fig. 3 and Fig. 4 The initial height of foam for concentration of 1.5wt% is a three-fold increase to that of a concentration of 0.5wt % (Refer to Fig. 3). This correlates with [11], [8] where higher surfactant concentration correlated with foam generation. Higher surfactant concentration also increases the stability of foam (Fig. 4). In experiments where salinity was fixed at 205000ppm and concentration varied at 0.5 and 1.5 wt%, no trend was observed in foam generation and stability time.

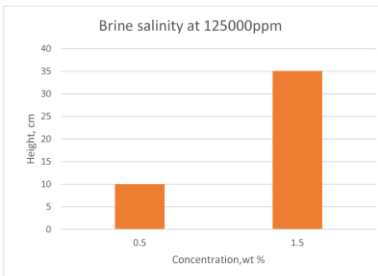

Fig. 3. Effect of surfactant concentration on foam generation.

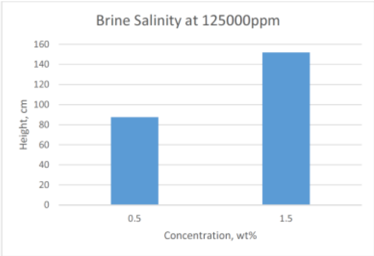

Fig. 4. Surfactant concentration effect on foam height.

3) Effect of mixing gas

These set of experiments were designed with fixed brine salinity of 165000ppm and surfactant concentration of 1 wt%. Different gas types (Nitrogen, Air and Carbon dioxide) were used for mixing or generating foam. The foam height and half-life were recorded.

In general Nitrogen gas foams generated more foams followed by CO_2 and lastly air (Fig. 5). Air has more stable time for the foams formed, followed by Nitrogen and lastly CO_2 foams breaks quickest (Times<2mins). We observed that the foam heights for CO_2 foams vary significantly for all three runs even though the brine salinity and surfactant concentration are fixed. A brief explanation for this behavior may lie in the bubble size of foams formed during gas mixing. Even though bubble texture/size studies was not a focus of this study, it was observed visually that among all the gases, CO_2 foams formed bigger bubbles during mixing. In research conducted by [12] small textured foams were found to be more stable than bigger textured foams. This assertion is confirmed in the foam stability times

Fig. 6 and Fig. 7 shows the height and stability times for experimental runs 2B, 2C and 3C using different mixing gases.

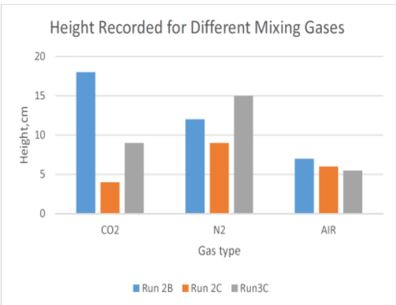

Fig. 5. Effect of mixing gas on foam generation.

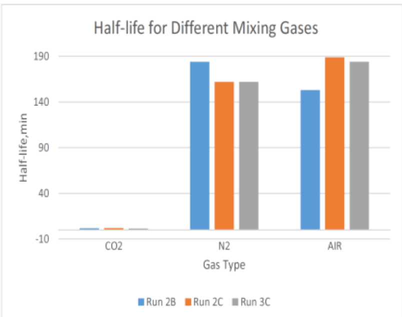

Fig. 6. Effect of mixing gas type on foam stability.

B. Effect of Crude Oil on Foam Generation and Stability

All sets of experimental runs conducted in the absence of oil were repeated in this section. The role of crude oil on foam generation and stability is mixed in the petroleum literature. Whereas some studies conclude positively for crude oil-foam interactions [13]-[15] others conclude that crude oil have negative effect on foam generation and stability[16]-[18].

4) Effect of brine salinity

The results in Fig. 7 and Fig. 8 compares the heights and half-life times for experimental runs 1A and 1B (Refer to Table II). Surfactant concentration is fixed at 0.5wt% and brine salinity is varied at 125000ppm and 205000ppm.

The same heights of foam were recorded for both salinities after mixing with nitrogen. Salinity had no effect on foam generation for both sets of experimental runs (1A and 1B) in the presence of oil. Comparison of foam heights in presence and absence of oil (see Fig. 7) reveals that, the foam breaks much quickly with lower salinity for Doumeen (TTM). A half-life of 10.58 mins was recorded for 205000 ppm and 5 mins for 105000 ppm. This shows that the higher salinity brine stabilizes the foam by approximately twice the time of lower salinity brine (105000ppm).

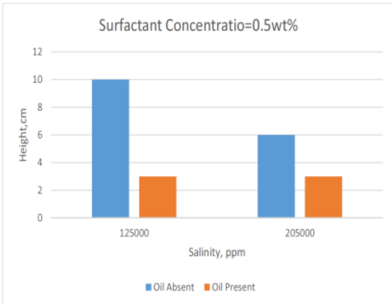

Fig. 7. Brine salinity effect on foam height in the presence of oil.

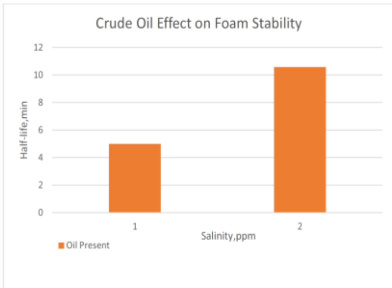

Fig. 8. Salinity effect on foam stability in the presence of oil.

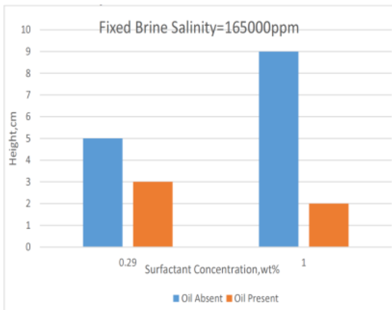

Fig. 9. Effect of surfactant concentration on foam generation in the presence of oil.

5) Effect of surfactant concentration

Experimental runs 1E and 2C were repeated with oil addition to observe the effects of crude oil on foam generation and stability. The salinity was fixed at 165000ppm and concentration of surfactant was varied at 0.29 and 1 wt%.

Varying surfactant concentration does not seem to have much effect on foam generation .Only a point difference was observed (See Fig. 9). Also the foam stability time is only three points more for high surfactant concentration in the presence of oil. Comparison of Fig. 4 and Fig. 10 reveals the vast difference in half-life between oil absence and presence. Fig. 9 and Fig. 10 shows the results obtained for foam height and stability respectively.

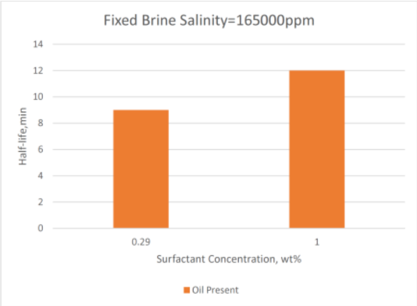

Fig. 10. Effect of surfactant concentration on foam stability in the presence of oil.

6) Effect of mixing gas

The effect of mixing gas type was repeated at a fixed brine salinity of 165000ppm and fixed surfactant concentration of 1 wt%. The comparison between absence and presence of oil on foam generation and stability are shown in Fig. 11 and Fig. 12 respectively. Foam heights and stability times for various mixing gases in the presence of oil was in the order of Air>Nitrogen>CO_2 (Fig.11). Foam heights and stability times in the absence of oil were much bigger than in the absence of oil (Fig 11 and Fig. 12).

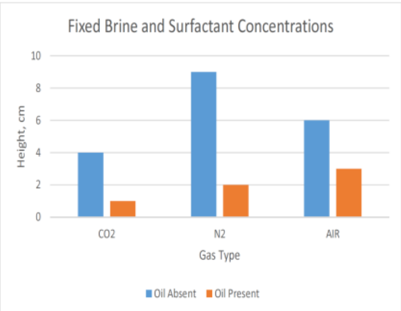

Fig. 11. Effect of mixing gas type on foam generation at fixed salinity and surfactant concentration.

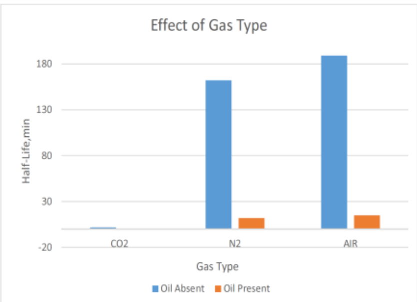

Fig. 12. Effect of mixing gas type on foam stability in the presence of oil.

IV. Conclusions

In the absence of oil, the following can be said:

1) Low salinities promote foam generation. However higher salinities (up to 205000ppm) stabilize foam for longer half-life.
2) Higher surfactant concentration generates more foams and also has longer stability than lower surfactant concentration.
3) Nitrogen as the mixing gas produces more foams and also the half-lives were higher for Nitrogen gas. This trend is followed by air and CO2 gas performs poorly.

Oil presence was detrimental on both foam generation and stability. The following are arrived at on the effect of parameters in the presence of oil:

1) Lower salt salinity generates more foams and high brine salinity stabilize foam than lower brine salinities. This trend was also observed in the absence of oil.
2) The effect of surfactant concentration on foam generation was not clear. Nonetheless, higher brine salinity stabilizes foam.
3) Air or Nitrogen as the mixing gas promotes more foam generation and foam stability. However, performance of CO_2 was not convincing in foam generation and stability at room conditions.

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